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GROWTH PATTERNS OF THE HUMAN PHYSIQUE: AN APPROACH TO KINETIC ANTHROPOMETRY

Part I

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["I believe the day must come when the biologist will—without being a mathematician—not hesitate to use mathematical analysis when he requires it."—Karl Pearson, in *Nature*, Jan. 17, 1901; quoted by D'Arcy Thompson, in *Growth and Form*, 1942.]

INTRODUCTION

ANATOMY is a process, not a state. This is most completely true before the body reaches "adulthood." At any time, then, it is the result of all previous living. In so far as it changes, ideally the changes are measurable. If the changes follow natural laws, they admit of formulation. The formulation is a description in the language of mathematics.

In anthropometry, the quantitative relationship between two dimensions of the body is expressed as a ratio, known as an index. In the statics of anthropometry, this is the only kind of index possible. But in the world postulated by the first sentence, two kinds are possible. The one is the relationship between a somatic dimension y and another one x; the other is the relationship between y or x and the time-dimension

t. x, y and t are changing continuously; hence the index can never be expressed as a mere single numerical quantity; rather, it is an algebraic formula, more or less complicated.[1]

The relationship between x and y I shall call a "somatic" index; that between y or x and t, a "parametric" index.

In this part of the study, we shall deal only with parametric indices, leaving somatic indices for Part II; except for one or two observations on somatic indices which will make clearer the biological significance of the parametric index.

A

The first of these two observations is an enlargement of the criticism recorded in the citation just made. Scammon and Calkins[2] have said:

> "The most important result of this work is the establishment of a new principle, that in general the linear growth of the various parts of the body is in uniform ratio during the fetal period. This seems at first glance to contradict the well-known fact that the proportions of the various regions change during this period, the lower limbs becoming relatively larger and the head relatively smaller. But the present study demonstrates clearly that these changes in proportion arise, in spite of the constant fetal growth ratios, through inequalities already established in the earlier embryonic period. The newly recognized law of uniform fetal growth ratios is shown to be in complete harmony with the previously known "law of developmental direction."

This treats of the kind of index, $y = f(x)$, which we shall examine in Part II. Nevertheless, both y and x—two given somatic dimensions—grow each with respect to time t. The pattern of this growth will determine the way in which the one (y) grows with respect to the other (x).

No one will dispute the fact that growth in time registers a curve for a graph. And I have yet to see such a curve for the fetal period which either tests out or appears by inspection to be other than curvilinear, probably exponential or logarithmic. That logarithmic curve is frequently likely to be of the very special type known as a skew logistic. Dr. Edith Boyd[3] has published unsurpassed examples of this type.

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[1] See HUMAN BIOLOGY, 14:2:143 ff.

[2] R. E. Scammon and L. A. Calkins: The Development and Growth of the External Dimensions of the Human Body in the Fetal Period. *Minneapolis*, 1929. Preface.

[3] Boyd, Edith. Outline of Physical Growth and Development. Burgess Publishing Co. *Minneapolis*, 1941.

Furthermore, I have never yet seen a curve of a somatic growth for the first few years of postnatal life that is not logarithmic; and that logarithm projects back *approximately* to o for the measurement at the time-point of conception. It is, however, well-nigh impossible to find data for one and the same measurement for both fetuses and infants of the same race and sex. It is quite likely, and is even boldly asserted by some investigators,[4] that the first years of postnatal growth continue the fetal curve. And yet, Scammon and Calkins have made an unequivocal claim in the passage cited. That claim rests on curves drawn admittedly by inspection. There is no indication, as far as I can find, that the line-fitting was done by the regular mathematical methods. And none of their straight lines in their field graphs fits their own constellations of samples—the one end or the other of their lines derails from the track of their data. In some cases they have, indeed, been under necessity of breaking off their straight line and resetting it in a slightly altered direction (see their field graphs nos. 25, 43, 44, 46, 47, 48). This should be enough to disprove their claim of a law of rectilinear ratios in growth. I think that the notion of rectilinearity is due to the fact that logarithmic or exponential curves are very gradual over parts of their travel; clearly so during the fetal period. But obviously the question of logarithm versus straight line is of more than theoretical importance—though theoretical importance is enough to validate the discussion. I wish therefore to analyze the matter a little further.

If two dimensions y and x preserve a constant ratio of growth between them according to the formula $y = ax + C$, then

$$\frac{dy}{dx} = a.$$

What, however, are the values of $\frac{dy}{dt}$ and $\frac{dx}{dt}$?

I have already remarked that probably or usually y and x are related to t logarithmically. Let $y = a_y + c_y \log t$, $x = a_x + c_x \log t$. Then

$$\frac{dy}{dt} = \frac{.4343c_y}{t}, \quad \frac{dx}{dt} = \frac{.4343c_x}{t}$$

and

$$\frac{\frac{dy}{dt}}{\frac{dx}{dt}} = \frac{dy}{dx} = \frac{c_y}{c_x}, \text{ which is a constant.}$$

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[4] See e.g. Portmann, A. Die Tragzeiten der Primaten. *Révue Suisse de Zoologie*, 48: 3: 511-517. *Basel*, 1941.

This would allow Scammon and Calkins to be correct. But empirical data are against this. A curve of the type $y = c \log t$ is too abrupt. At least one more term needs to be introduced; and we have

$$y = a_y + b_y \cdot t + c_y \log t$$

$$x = a_x + b_x \cdot t + c_x \log t$$

From these we get

$$\frac{dy}{dt} = b_y + \frac{.4343 c_y}{t}$$

$$\frac{dx}{dt} = b_x + \frac{.4343 c_x}{t}$$

and

$$\frac{\frac{dy}{dt}}{\frac{dx}{dt}} = \frac{dy}{dx} = \frac{b_y t + .4343 c_y}{b_x t + .4343 c_x}.$$

Unless $b_y = b_x$ and $c_y = c_x$, this ratio cannot equal a constant; therefore y and x cannot grow in a constant ratio, and cannot plot a straight line.

If $b_y = b_x$, $c_y = c_x$, then the only difference between the values of y and x come from a_y and a_x: y and x would plot as parallel curves against t. This is not an impossible situation, but it would be an exceptional one. It is not the situation in the case of Scammon and Calkins' data.

In my previous paper, two dimensions, postnatal to be sure, responded to the formula x or $y = a + bt + c \log t$; when their ratio was taken, they yielded the formula $y = ae^{bx}$; whence $\frac{dx}{dy} = abe^{bx}$. It would seem, aprioristically to be sure, that fetal growth would hardly follow a principle of rectilinearity and then undergo a radical alteration postnatally to an exponential one.

I have said above, that parallel growth-lines are not impossible. I mean that, over a stretch of time, for instance from birth to age 6, one might find two logarithmic curves running approximately parallel, so that when the parameter t (time) is eliminated and y is plotted against x, the result is practically a straight line. But if we had the prenatal data as well, it is likely that our two postnatal curves would turn out to be fragments of the long arms of skew logistics of the type

illustrated by Dr. Edith Boyd; in which event the failure of our two fragments to coincide approximately would be due to a disparity in the short arms of the skew logistics which occur in the initial months of prenatal life. The formula for the skew logistic would be

$$y \text{ or } x = \frac{K}{1 + C \text{ antilog } [k \cdot f(y \text{ or } x)]} + d;$$

so that again $\frac{dy}{dx}$ could not be a constant. The straight-line relationship would then exist only approximately over a part of the length of the mutual locus of x and y.

B

In Figs. 1 and 2 (A and B), I have introduced some sample curves where one somatic dimension is plotted against another. The equations are immaterial until we come to Part II; the fact that the curves are unruffled by growth spurts is important. It relegates any growth spurts to the other kind of index—a somatic dimension plotted against time. Fig. 1 would picture the growth-pattern of the height-weight index It is important to note that *the same formula which would fit in childhood is still the formula that obtains at completion of stature—the body-*

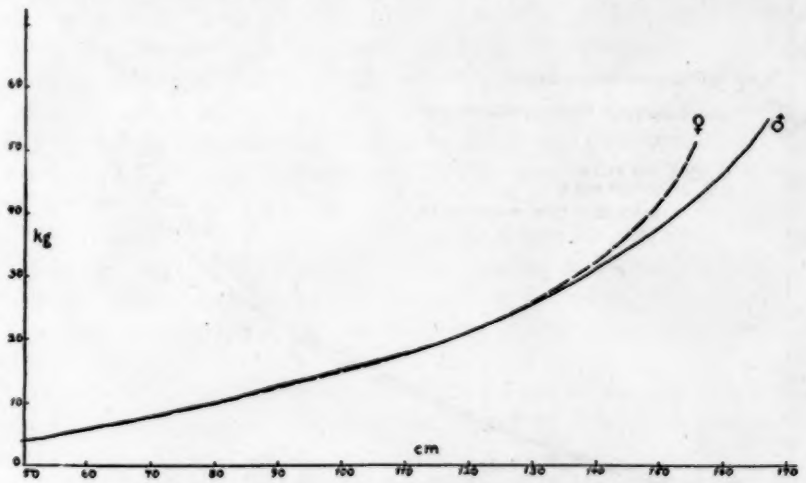

FIG. 1. CHINESE—NEW BORN TO ADULT. MALE AND FEMALE
(Data of Wu and Soong.)
y = weight; x = stature.

build seems to have been planned already as far back as the data carry us. There is no change, for instance, at the onset of puberty, and during acceleration of growth in adolescence.

The height-weight index is a common one in static anthropometry. But the kinetic viewpoint brings out what may be taken as a flaw.

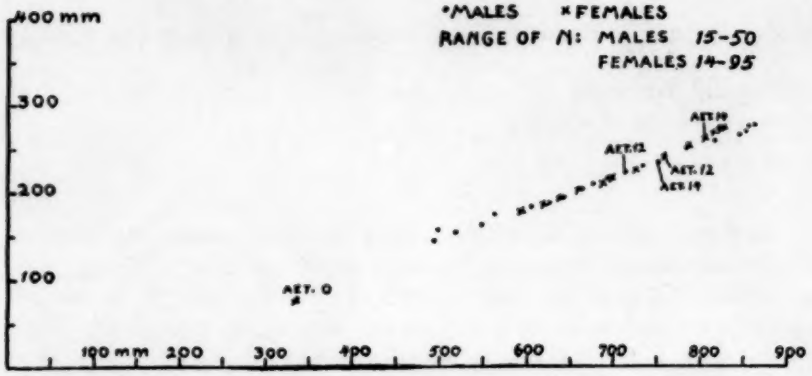

FIG. 2A. PELVIC BREADTH/TRUNK LENGTH IN SOUTH RUSSIAN JEWS
(Data of Weissenberg.)

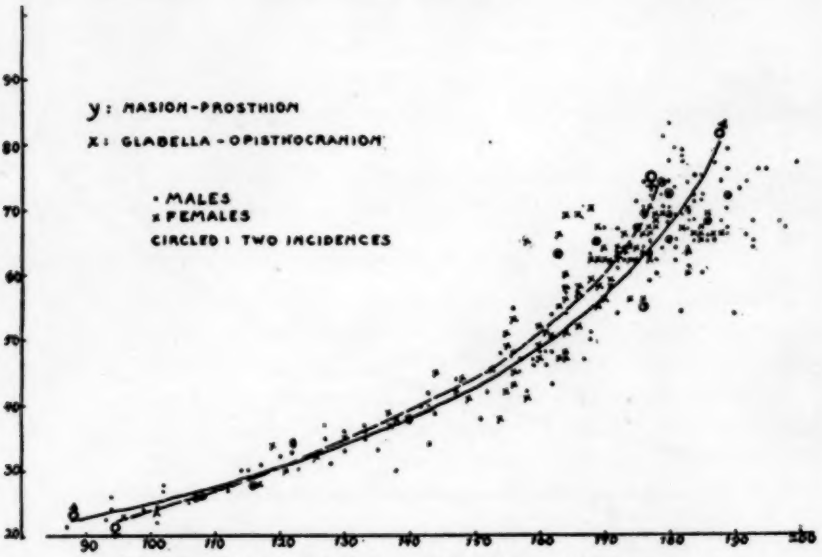

FIG. 2B. BALSATIAN CRANIA—NEW BORN TO OLD AGE
(E. Adam's Data.)

Weight obviously is partially correlated positively with height.[5] When we trace a curve of relationship between height and weight, we really have plotted stature against some product of stature-breadth-depth—thus introducing a dash of "spurious correlation." But at least breadth and depth have not "jogged" our line anywhere, though shoulder-breadth, for instance, is known to increase in a rate different from stature, and it continues after stature-velocity has reduced to zero.

To bolster my argument, therefore, I have introduced Figs. 2A and 2B. While both dimensions naturally increase during the growth-period, at least one is not part of the other. Again we have some kind of exponential curve—the formula does not matter here—showing absence of "spurting" in the line at any age-point.

C

And so we come to examining the parametric index, $y:t$ (see Figs 3 and 4).

There are many, many curves in the literature which plot various dimensions over a period of time. But no descriptive formulae are given. A graphed curve without a formula is an indicator-hand unbacked by a dial. That the indicator swings or oscillates is quite visible; but its behavior cannot be read.

On the other hand, a portion of a line, especially when the line seems irregular in its bends, is inadequate for constructing the dial. Nothing less than data from birth to adulthood will suffice—it were better to start far back in the prenatal period; but we must not be unreasonable—and the samplings must be large, the sexes reported separately, the populations sufficiently homogeneous so that bimodality of hybridization will not disturb the course.

As standard I have therefore chosen the means for stature in Chinese as reported by Wu and Soong.[6] The reliability or limitations of these data the reader may judge for himself by consulting the reference. They are quite adequate for our purposes, and as valuable as their ilk is rare.

I must add that I have examined the curves of many sets of data, from different parts of the body, and more or less extensive in the

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[5] Among adult male Cantonese, r for height and weight is given as +.551. See Uttley in *Trans. Roy. Soc. Trop. Med. and Myg.*, 35 (4): 223-228, 1942.

[6] Wu, C. H., and Soong, S-C. The growth rate of Chinese. *Amer. Jour. Phys. Anthrop.*, 28: 4: 357-373, 1941.

growth-period they cover. In all cases where the data of the means given by the collectors did not plot zigzag courses that defeated attempts to smooth them down, the curves examined would not negate the presumption that the principles fitting the specimens now to be examined apply generally.[7] Consider Figs. 3 and 4.

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[7] The type of curve about to be analyzed fits excellently the following—their differences naturally being quantitative (sexes always separatim):

Stature in southern Russian Jews, male and female (data of Weissenberg);
Shoulder breadth in southern Russian Jews, male and female (Weissenberg);
Pelvic breadth in southern Russian Jews, males (Weissenberg);
Stature in Belgians, male and female (Quetelet);
Weight in Chinese, male and female (Wu and Soong).

The following fit excellently as far as their data go; but incompleteness at this age or that would preclude their use in establishing basic norms, nevertheless they afford very good corroboration within their limits:

Pelvic breadth in southern Russian Jews, female (Weissenberg; data lacking for ages 1-5, yet including age 0);
Stature in Michigan Dutch, male and female (Steggerda, unpublished; ages 6-18 available);
Weight in Michigan Dutch, male and female (Steggerda, unpublished; ages 6-18 available);
Stature in U.S. white children, male and female (Collins and Clark; ages 7-15 available).

The following contain one or more age-classes which deviate from a smoothed curve sufficiently to make a "jog" or zig zag at a certain spot or two, otherwise a smoothed curve could be fitted:

Cephalic length in Holsteiners, male and female (Ranke);
Cephalic breadth in Holsteiners, male and female (Ranke);
Cephalic length in Schaffhausen Swiss, male and female (Schwerz).

The following zigzag too strongly for direct analysis; and yet a curve of the nature under study can be run comfortably through the field:

Cephalic length in white American males (West; the locus is good up through age 13, but the adolescents zigzag);
Stature in Melanesians, male and female (Reche; apparently the universe was too meager).

The Negroes of Herskovits demand special mention:

The stature curves, male and female, are very smooth, and the present analysis would suit them well, except for mid-adolescence in males. But Herskovits admits specifically that his populations were hybridized. I suspect, therefore, that the curves indicate certain modalities that result from a racial blending. The possibility is suggestive for future comparisons.

The same characterization applies to sitting-height;

Apparently also to head length in males, except for one "jog" at age 4;

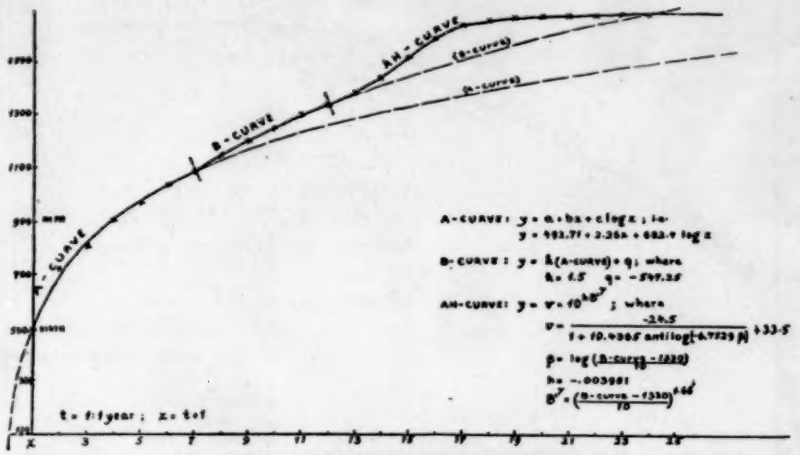
A-CURVE
B-CURVE
AH-CURVE
(B-curve)
(B-curve)
A-CURVE: y = a + bx + c log x ; i.e.
y = 992.71 + 2.26x + 682.7 log x
B-CURVE: y = h(A-curve) + q ; where
h = 1.5 q = -597.25
AH-CURVE: y = v·10^(kB') ; where
v = -24.5 / (1 + 10.9365 antilog[4.7729 p]) + 33.5
p = log (B-curve − 1222)
k = −.003981
B' = ((B-curve − 1310)/10)^4.4
t = 1 if year ; x = t+1

FIG. 3. CHINESE MALE STATURE
(Data of Wu and Soong.)

In each, the curve breaks up into three parts, *and no fewer,* as far as indicated by any formulation I have been able to attempt.

The first part ("A") is a common type of logarithmic: $y = a + bt + c \log t$. (For simplicity in computation, however, I have substituted $x = t + 1$ and have calculated the a, b, c values as per $y = a + bx + c \log x$). The curve would project back to intercept

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Head length in females zigzags too much, but does not preclude consistency with the foregoing if a smoothed curve be passed through the data;

Head breadth in males shows the same degree of reliability as head length;

Male cephalic modulus $\left(\frac{L + B + H}{3}\right)$ and the cephalic cube-root modulus $\left(\sqrt[3]{L + B + H}\right)$ are likewise not inconsistent, except for jogs at ages 2 and 3, 16, 17, 18, 19;

Female cephalic modulus is a better fit than the male except for adolescent years, where the line zigzags;

Bizygomatic width curve is most nearly "canonical" in its configuration.

Herskovits believes that the zigzags are due to inadequacy of numbers, not to differences in the race-compositions of the series for each age. He may be right. But even if so, the smoothed curves—and his stature curves *are* smooth—deviate sufficiently in adolescence, as already mentioned, from the stock type to suggest that a curve for as radically hybrid a population as the American colored will reflect that hybridization. But a comparative study of hybrids as against "pure" stock (let the sense of that term be broad) must await a later opportunity.

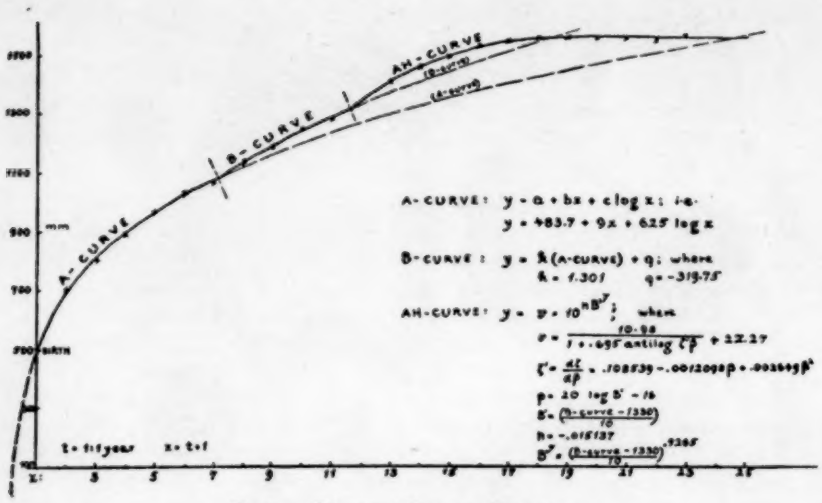
A-CURVE
B-CURVE
AH-CURVE
A-CURVE: y = a + bx + c log x; i.e.
y = 483.7 + 9x + 625 log x
B-CURVE: y = k(A-curve) + q; where
k = 1.301 q = -319.75
AH-CURVE: y = v = 10^(nB^γ); where
n = 10.98 / (1 + .695 antilog ζβ) + 22.27
ζ' = dζ/dβ = .108539 - .00120938β + .0026493β²
β = 20 log B' - 16
B' = (B-curve - 1330)/10
h = -.015137
B^γ = ((B-curve - 1330)/10)^.9265
mm
birth
t = 1/1 year
x = t+1

FIG. 4. CHINESE FEMALE STATURE
(Data of Wu and Soong.)

the abscissa at about conception time. (This, however, as I have pointed out before, is probably a fault; for, as Dr. Edith Boyd has indicated for fetal curves, they should probably be skew logistics with a very short lower arm and an inflectional point after the first few weeks of gestation. But the inaccuracy is not effective within the limits of our own study.) The implication is, that the A-curve continues postnatally the prenatal formula.

At about first-molar time—we may say, during the period of final construction of this molar plus its eruption—until about second-molar time, there is a simple step-up of velocity implied in the equation B-curve $= y = k$ (A-curve value) $+ q$.

The AH-curve then supravenes, and flattens out at about the time of third-molar activity so that the AH-curve $= y = ve^{\rho B^{\gamma}}$, where v itself is a logistic with respect to the B-curve (see Tables 1, 2, 3, 4).

Now, had there been no alteration in rate from inception on—had the A-curve alone continued to obtain—eventually, full stature would have been reached, decades later, as witness the projection of A on the graph. And nothing in the shape of the curve itself would have shown stoppage of growth. This, it seems to me, would have simulated the growth pattern of animals neither warm-blooded nor having the mammalian tooth system; reptiles, or something even more lowly. It is, I

TABLE 1

Summary of the formulary for statural growth in male Chinese

I. A-curve:

$$\overline{A} = a + bx + c \log x$$

$a = 492.71$
$b = 2.26$
$c = 682.4$
$x = t + 1$
$t =$ time in years

Limits: *ca.* $x = .25$ to *ca.* $x = 7+$

II. B-curve:

$$\overline{B} = k\overline{A} + q$$

$k = 1.5$
$q = -547.25$

Limits: *ca.* $x = 7+$ to *ca.* $x = 12+$

III. AH-curve:

$$\overline{AH} = 1680 - 10AH'; \; B = 1330 + B'$$

$$AH' = \frac{1680 - \overline{AH}}{10}; \; \frac{B' = \overline{B} - 1330}{10}$$

$$AH' = v\epsilon^{\rho B'^{\gamma}}$$

or

$$AH' = v \text{ antilog}_{10} hB'^{\gamma}$$

$h = b(r^e - 1)$, where $r = 2$,
$= -.003981$
$\gamma = 1.66$
$\rho = 2.303h = -.00918$

$$v = \frac{K}{1 + C\epsilon^{R\beta}} + d, \text{ or}$$

$$= \frac{K}{1 + C \text{ antilog}_{10} m\beta}$$

$K = -24.5$
$d = 33.5$
$m = -6.7529$
$C = 10.4365$
$\beta = \log_{10} B' - 1.000$
$R = 2.303m = -15.55$

Limits: *ca.* $x = 12+$ to *ca.* $x = 24-$

TABLE 2

Summary of the formulary for statural growth in female Chinese

I. A-curve:

$$\overline{A} = a + bx + c \log x$$

$a = 483.7$
$b = 9$
$c = 625$
$x = t + 1$
$t =$ time in years

Limits: *ca.* $x = .25$ to *ca.* $x = 7.4$

II. B-curve:

$$\overline{B} = k\overline{A} + q$$

$k = 1.301$
$q = -319.75$

Limits: *ca.* $x = 7.4$ to *ca.* $x = 12$

III. AH-curve:

$$\overline{AH} = 1680 - 10AH'; \quad B = 1330 + B'$$

$$AH' = \frac{1680 - \overline{AH}}{10}; \quad \frac{B' = B - 1330}{10}$$

$$AH' = v\epsilon^{\rho B'^{\gamma}}$$

or

$$AH' = v \text{ antilog}_{10} hB'^{\gamma}$$

$h = b(r^e - 1)$, where $r = 2$,
$= -.015137$
$\gamma = .9265$
$\rho = 2.303h$

$$v = \frac{K}{1 + C\epsilon^{R\beta}} + d, \text{ or}$$

$$= \frac{K}{1 + C \text{ antilog}_{10} m\beta} + d$$

$K = 10.98$
$d = 22.27$

$$m = \frac{d\zeta}{d\beta} = \zeta'$$

$\zeta' = .108539 - .0012098\beta + .002649\beta^2$
$\zeta = -.156474 + .108539\beta - .0006048\beta^2 + .000883\beta^3$
$C = .695$
$\beta = 20 \log B' - 16$
$R = 2.303m$

Limits: *ca.* $x = 12$ to *ca.* $x = 18.4$

TABLE 3

Empirical and calculated values for statural growth of Chinese males

Empirical data of Wu and Soong. See Figure 3.

AGE $= t$	$x = t + 1$	CURVE A (*mm.*)			CURVE B (*mm.*)			CURVE AH (*mm.*)		
		Empir.	Calc.	A calc. / A empir.	Empir.	Calc.	B calc. / B empir.	Empir.	Calc.	AH calc. / AH empir.
0	1	495	494.97	1.000	....	.....	....	....	.....	.....
1	2	724	702.43	.971	....	.....	....	....	.....	.....
2	3	805	824.79	1.021	....	.....	....	....	.....	.....
3	4	905	912.65	1.008	....	.....	....	....	.....	.....
4	5	966	980.81	1.022	....	.....	....	....	.....	.....
5	6	1035	1036.77	1.001	....	.....	....	....	.....	.....
6	7	1085	1085.03	1.000	....	.....	....	....	.....	.....
7	8	....	1121.79	....	1142	1142.75	1.000	....	.....	.....
8	9	....	1163.85	....	1201	1199.25	.999	....	.....	.....
9	10	....	1197.71	....	1253	1248.75	.997	....	.....	.....
10	11	....	1228.57	....	1296	1295.25	1.000	....	.....	.....
11	12	....	1256.33	....	1334	1332.75	.9985	....	.....	.....
12	13	....	1277.59	....	....	1367.75	....	1380	1376	.998
13	14	....	1306.35	....	....	1411.75	....	1440	1436	.998
14	15	....	1329.61	....	....	1445.25	....	1519	1511.5	.996
15	16	....	1351.37	....	....	1476.75	....	1588	1590	1.001
16	17	....	1371.13	....	....	1508.75	....	1634	1636	1.001
17	18	....	1389.89	....	....	1535.25	....	1654	1652.8	1.001
18	19	....	1408.15	....	....	1562.75	....	1663	1662.1	1.000
19	20	....	1426.91	....	....	1592.75	....	1664	1668.33	1.017
20	21	....	1443.17	....	....	1616.75	....	1668	1671.7	1.002
21	22	....	1458.93	....	....	1639.75	....	1676	1674+	1.000

dare say, no coincidence that the first human growth-spurt occurs when also the first molar is completed. But the spurt is simplex.

The B-curve likewise has been projected. But here growth has been so speeded up that this curve would achieve adult stature at about the time it actually is reached via the AH-curve. However, again the curve might continue on indefinitely after that into giantdom.

The AH-curve is as interesting as it is complex. Growth is markedly speeded up, beginning at about second-molar time; but the acceleration

TABLE 4

Empirical and calculated values for statural growth of Chinese females

Empirical data of Wu and Soong. See Figure 4.

AGE = t	$x = t+1$	CURVE A (mm.)			CURVE B (mm.)			CURVE AH (mm.)		
		Empir.	Calc.	A calc. / A empir.	Empir.	Calc.	B calc. / B empir.	Empir.	Calc.	AH calc. / AH empir.
0	1	484	492.7	1.0175	....	.....	....	....	.....	.....
1	2	703	689.6	.982	....	.....	....	....	.....	.....
2	3	805	808.9	.953	....	.....	....	....	.....	.....
3	4	891	895.9	1.006	....	.....	....	....	.....	.....
4	5	971	965.2	.985	....	.....	....	....	.....	.....
5	6	1026	1023.7	.999	....	.....	....	....	.....	.....
6	7	1072	1074.9	1.003	....	.....	....	....	.....	.....
7	8	....	1120.2	....	1136	1137.25	1.002	....	.....	.....
8	9	....	1160.7	....	1184	1190.25	1.005	....	.....	.....
9	10	....	1198.7	....	1246	1240.25	.997	....	.....	.....
10	11	....	1233.7	....	1280	1285.25	1.004	....	.....	.....
11	12	....	1272.2	....	1328	1327.25	1.000	....	.....	.....
12	13	....	1297.2	....	....	1369.25	....	1403	1399.3	.9973
13	14	....	1325.7	....	....	1404.25	....	1459	1458.2	.9994
14	15	....	1353.7	....	....	1441.25	....	1496	1504.9	1.0059
15	16	....	1380.7	....	....	1477.25	....	1526	1532.05	1.004
16	17	....	1406.2	....	....	1510.25	....	1546	1546.3	1.0002
17	18	....	1430.7	....	....	1540.25	....	1551	1555.8	1.00309

very soon becomes a strong deceleration; so much so that growth is actually braked to a stop—at about third-molar time.

(1) The AH-curve, moreover, is patently a form of logistic: whatever catalytic forces bring to bear upon the older growth-pattern, their inception, climacteric, extinction harmonize with theories of organic growth.

The rationale of the adolescent spurt thus would seem to be (1) to bring the mammal to adult stature in the early period of life, (2) to make definitive an adult stature. And since, when one dimension y is plotted against another x, the curve is regular from birth to adulthood, the increases in speed of growth so easily recognized at adolescence clearly do *not* alter relationships between bodily dimensions but merely telescope the

time in which the growth-patterns is worked out by a formula obtaining at least back to time of birth. As far as I know, the above-numbered conditions do not obtain among lower forms of vertebrates; nor, for that matter, is there so definite a life-span.

Thus far, what has been said applies to both sexes. But there are interesting differences. The most spectacular, of course, is the quantitative preponderance of the male AH-curve. The female, however, happened to be the harder to evaluate: the v-factor turned out to be a skew logistic, whereas the male gives a satisfactory fit out of a symmetric logistic for v. I have no idea as to the significance, if there be any.

But sex differences hark back at least to birth. It does not seem an accident of calculation that the female curve at first lies slightly below the male. Its curvature presumably initiated at conception, is a shade flatter than the male; but, were both sexes to continue growing only via the A-curve, soon the female would begin to outstrip the male. This again recalls the condition among many lower forms. Aside from the careful check I have made on my formulation, it should be obvious that two logarithmic curves starting at origin and curving the way the empirical data declare they do, should actually cross eventually. Apart from this, however, Wu and Soong themselves observe that, while the females at this early period are very slightly smaller than the male, they actually are putting on a measurably greater per cent increment.

But this apparently significant difference of behavior would not have appeared out of the usual type of statistics. Had the means at the several age-levels under scrutiny been tested for significant differences by way of the x P.E., no significance would have been found. This, I think, is noteworthy.

When the B-curves of the sexes are compared, the most obvious feature is that the female for a brief period actually does stand higher than the male.

It would be pedantic to tabulate here the theoretical values obtained by projecting the A-curve and the B-curve indefinitely. Let the broken lines on Figs. 3 and 4 do; and suffice it to say that, were the values for the male A-curve plotted against those of the female, we should have subequal stature in the sexes until age 7, with the male slightly preponderating; after that, the female would slowly pull ahead of the male. The B-curves are such that practical equality of stature would be maintained until subadulthood (the speed of growth in both sexes having been accelerated); thereafter the female would very gradually pull

ahead. What actually does happen is the supravention of the AH-curve; the result being that, starting with equal stature at age 11, the female gains precociously over the male, and is the taller at ages 12 and 13; thereafter the male starts to catch up; before age 14, he is already becoming spectacularly the taller; and by age 17+, when the female gives up the race entirely, the male has won hands down.

The sexual difference in the AH behavior seems to have only dimly surmisable significance. The male outburst is tremendous as compared with the female. On the one hand, the female is slowly catching up to and heading into outstripping the male; yet her growth-acceleration, while moderate, seems quickly to exhaust the growth potential and bring her stature to a stasis at a compartively low mark; and yet her AH-curve hardly levels off to the horizontal before it is crossed by her B-curve as projected theoretically. The male contrast is obvious. In the end, however, he also slows gently to a stop; only at a higher level in the millimeter scale at a somewhat more advanced age.

The sex ratios would undoubtedly be more interesting if we were in a position to compare Nordics, Alpines, Crô-Magnon men, Negritos, Shilluk, Eskimo, Dyaks, Neanderthalers, Peking men; to say nothing of anthropoid apes and other primates.

The behavior of the male growth in stature summarizes thus:

Assuming the validity of the calculations,

Actual adult stature would have been reached via the A-curve alone at *ca. aet.* 35 years±;

By way of the B-curve step-up, at *ca. aet.* 22.8;

It actually is achieved via the AH-curve step-up at *ca. aet.* 22+.

The AH curve therefore does not materially hasten "adult" stature over the theoretical for B; it speeds up growth during *early* adolescence, and *slows* it in later adolescence; the process is stopped at *ca. aet.* 22+.

The behavior of the female growth in stature summarizes thus:

Assuming the validity of the calculations,

Actual adult stature (which is lower than the male) would have been reached via the A-curve alone at *ca. aet.* 23.6 years;

By way of the B-curve step-up, at *ca. aet.* 17.4;

It actually is achieved via the AH-curve step-up at *ca. aet.* 18—.

The AH curve therefore does not hasten "adult" stature over the theoretical for B; it speeds up growth during *early* adolescence, and slows it in later adolescence; the process is stopped at *ca. aet.* 18—.

In the suggestive mood—were this behavior discovered to be but a special instance within a more general mammalian pattern, then the

curve would be a dramatization of the interaction between growth-promoting and growth-inhibiting forces. There exists a marked sex discrepancy. We must break off here—in the face of a tantalizing speculation. For reptilian females are the bigger bodied sex; otherwise, as far as I know, the secondary sex characters are not as pronounced as in many mammals. One would add to the various masculine bodily luxuriations of mammals a growth step-up at puberty which renders the males the larger, besides the more spectacular, sex.

Discussion of the character of the curves

The formulations must stand on their own merits. Tables 3 and 4 demonstrate that the equations developed provide a very close fit to the data. Since, however, there are various other interpretations of human growth-curves, some further comments are called for.

Davenport[8] once spoke of two autocatalytic cycles of human growth in weight; he particularly described the processes in terms of velocities that were exponential in nature; he saw a maximum velocity at about birth, with a rapid drop thereafter to an approximate level from 3½ to 6½ years; then a rise from 8½ to 10 years, with a new maximum (in males) at 15 years. Since I have already pointed out that the curve of weight-growth behaves like that for stature, the following remarks are pertinent: The present curves, both for males and females, obviously show a rapid change in direction at about birth. In mathematical terms, the radius of the curvature of the evolute of the parent curve at that time is about at a minimum. And the curves themselves demonstrate that the velocity of growth is pretty level from ages 3½ to 6½. So that there is no conflict here between Davenport's description and the present mathematical analysis. Davenport, too, noticed the increase which places at ages 8½ to 10. This falls in the province of my B-curve.

Without having gone over Davenport's description at the time, I had experimented a good deal with the line from about age 7 to adulthood, attempting to fit it to a single equation. I had wasted a great deal of time and effort before the curve seemed to fall apart into the two sections—the B and the AH—which readily lent themselves to the interpretation I have developed. The B-portion of the curve simply does not bend properly to fit satisfactorily any formula I have been able to attempt for the A- and the AH-sections.

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[8] Davenport, C. B. Human growth curve. *Jour. Gen. Physiol.*, 10:2(1926): 205-216.

At best, none the less, the formulations here offered are but approximative descriptions. Thus, Boyd's[9] data would indicate that the A-curve actually is a skew logistic (or something similar), with a very short lower arm in the early weeks of prenatal life. The longer arm should reach outward and upward to some undetermined upper asymptote. But there can be no abrupt changeover in actual life from the A to the B curve, no definite point on the t-scale where one ceases and the other begins. I have built up the B-curve in terms of the A-curve, and later used in like manner the B-curve as the base of reference for the AH-curve. This was not merely convenient mathematics; it had, I think, sound biological theory back of it. For any step-up in velocity must be a step-up over the rate obtaining just previously. But if the B-curve diverges from the A-curve it must start gradually, imperceptibly. Again we probably should have a very skew logistic, had we the proper magnifying-lens for scrutinizing the intimate behavior; and the initial, lower arm might be very short, as in the fetal period. The long, upper arm is what I have described, as in the case of the A-curve, in terms of a simple logarithmic formula; again we may suspect some undetermined upper asymptote. And finally, the AH-curve is manifestly a logistic, basing upon the B-curve; though the skewness is not very strong (but there is a sex difference). The biological complexion of this changeover to a far less asymmetric logistic is unknown to me, of course; but it affords grounds for interesting speculations. Perhaps some day some insight will come by way of an inversion of our variables, such that the y-factor would be treated as the independent variable, acceleration be scaled in constant units, and the t-factor be treated as the dependent variable . . . But that is still in the lap of the gods. Returning to earth—the growth curve from conception to adulthood seems actually to reflect three pulsations, each a skew logistic built upon a preceding one. There is nothing unreasonable about this; in fact, a logarithmic growth is what one would expect. And if we may justifiably project the line back, then early postnatal growth is an undisturbed continuation of the prenatal.

Adolf Portmann[10] has discussed recently an aspect of this matter. He has attempted to account for the peculiar helplessness of the human infant as against that of other mammals, particularly anthropoids; and

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[9] *Loc. cit.*

[10] Adolf Portmann, Die Tragzeiten der Primaten. *Revue Suisse de Zoologie. Basle.* 48: 3: 511-517. August, 1941.

he considers that the human has reached the equivalent development of the natal ape by about age 1 year postnatum. Be that as it may, he points suggestively to v. Lange's (1905) observation that human stature takes on its "characteristic manner" of growth only after age 1 year; to Scammon's (1922) similar observation, coupled with the further one that increase in weight continues postpartum to follow "fetal laws."[11]

The rejoinder here must be that none of Wu and Soong's data support these observations which appear descriptive only. Our Fig. 1, which has plotted weight against stature simply because these two quantities are described as to their mutual relationships by Wu and Soong, and because both are treated to graphs by these authors, which graphs show parallelisms, has shown a regularity of their growth which follows an exponential guide. (See Part Two of the present study.)

I suspect that the reason why a change in growth behavior has sometimes been claimed for the period around age 1 year, is that the logarithmic curve shows its most abrupt bending at about this time. As I have remarked, here its evolute has the shortest radii of curvature—a piece of mathematical ideation which some day may be very useful to the physical biologist, particularly the growth analyst. But such rapid change in slope of the growth curve does not in the slightest indicate a change in growth pattern. It means that growth rate is slowing down very rapidly at this time; or, what is saying the same thing in a different way—the time-dimension is lengthening out rapidly.

D

Velocities of growth

The velocities may be derived by calculus from the pattern-formulae. For the A and the B curves this is a simple matter; for the AH-curve, it is complex.

We might go further and seek the accelerations. The formula is easily derived $\left(\frac{d^2y}{dx^2}\right)$ for the A- and B-curves; for the AH-curve, it is of astronomical proportions, and is therefore impracticable; at least, in the present state of our knowledge, its use would not be commensurate with the effort of calculating it.

If the A and B curve are easily handled, it is only because they have been fitted to logarithmic formulae of almost the simplest type.

[11] *Vide* Portmann.

But if, as I have already pointed out, the A and B curves are really extremely asymmetrical logistics, then their velocities would have to be expressed in a much more complicated form than I have done here. This, of course, would not render the numerical values of velocities at most ages significantly different from those set down in Tables 5 and 6.

These values are graphed in Fig. 5.

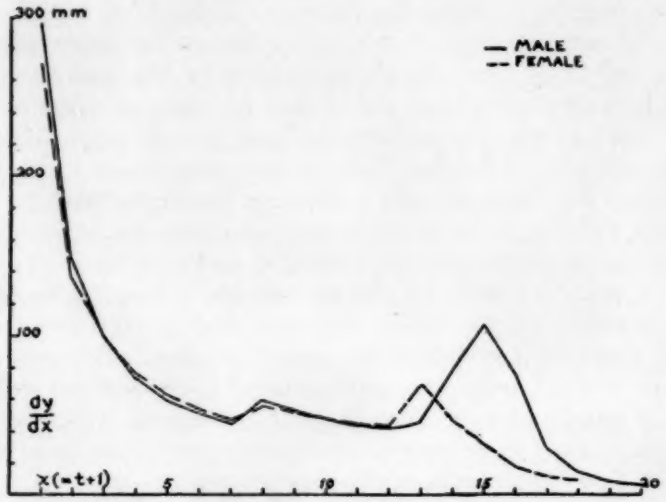

FIG. 5. VELOCITIES OF GROWTH—CHINESE

The general skylines of the graphs are not much different from Davenport's for weight.[12] They resemble also, even to certain details, the lines traced by Wu and Soong in their Fig. 3 (*op. cit.*) for the relative growth in stature computed in terms of yearly per cent increment.

The velocities of the A-curves, naturally, are of the conformation $y = b + cx^{-1}$; of the B-curves, the conformation is $k\ (b + cx^{-1})$, where $k > 1$. When the sexes are superimposed, a definite behavior seems to emerge. The female velocity at birth is less than the male; but the deceleration is slightly more gradual, until ages 4 and 5 the female velocity is a little higher than the male. Sometime shortly after, they both accelerate, the male jumping up to a slightly higher velocity than the female. Again the process repeats. (This is inherent in the formula used, since the B-curve is merely a constant multiple of the A-curve;

[12] *Loc. cit.*

TABLE 5

*Velocities of growth: Male**

A-curve: $\frac{d}{dx}(A) = b + \frac{.4343c}{x}$

t	$x = t + 1$	*Velocity in mm.*
0	1	298.26
1	2	150.26
2	3	101.06
3	4	76.26
4	5	61.51
5	6	51.66
(6)	(7)	(44.56)
(7)	(8)	(39.31)

B-curve: $\frac{d}{dx}(B) = k\left(b + \frac{.4343c}{x}\right)$

6	7	66.87
7	8	58.97
8	9	52.77
9	10	47.87
10	11	43.77
11	12	40.45
(12)	(13)	(37.57)

AH-curve:

$$\frac{d}{dx}(AH) = \begin{cases} -\left[\left(\frac{K}{1 + Ce^{R\beta}} + d\right) \cdot e^{\rho B'^{\gamma}} \cdot \rho\gamma \cdot B'^{(\gamma-1)} \cdot k\left(b + \frac{.4343c}{x}\right)\right] \\ -\left[e^{\rho B'^{\gamma}} \cdot \frac{-KCRe^{R\beta}}{(1 + Ce^{R\beta})^2} \cdot \frac{.4343}{B'} \cdot k\left(b + \frac{.4343c}{x}\right)\right] \end{cases}$$

12	13	45.495
13	14	79.2
14	15	105.8
15	16	75.37
16	17	28.96
17	18	13.17
18	19	7.054
19	20	4.285
20	21	2.9456
21	22	2.0543

* Values of algebraic symbols as in Table 1.

TABLE 6

*Velocities of growth: Female**

A-curve: $\frac{d}{dx}(A) = b + \frac{.4343c}{x}$

t	$x = t + 1$	*Velocity in mm.*
0	1	280.3
1	2	144.7
2	3	99.5
3	4	76.9
4	5	63.35
5	6	54.25
(6)	(7)	(47.8)
(7)	(8)	(42.9)

B-curve: $\frac{d}{dx}(B) = k\left(b + \frac{.4343c}{x}\right)$

6	7	62.25
7	8	55.87
8	9	51.—
9	10	47.+
10	11	43.8
11	12	41.16
(12)	(13)	(38.9)

AH-curve:

$$\frac{d}{dx}(AH) = \begin{cases} -\left[\left(\frac{K}{1 + Ce^{R\beta}} + d\right) \cdot e^{\rho B'^{\gamma}} \cdot \rho\gamma \cdot B'^{(\gamma-1)} \cdot k\left(b + \frac{.4343c}{x}\right)\right] \\ -10e^{\rho B'^{\gamma}}\left[\frac{-2.303KCe^{R\beta}}{(1 + Ce^{R\beta})^2} \cdot \left\{m\left(\frac{.8686}{B'}\ k\ \left(b + \frac{.4343c}{x}\right)\right)\right.\right. \\ \left.\left. + \beta(-.0012098 + .005298\beta)\right\}\right] \end{cases}$$

12	13	69.38
13	14	46.97
14	15	32.32
15	16	16.055
16	17	11.545
17	18	10.07

* Values of algebraic symbols as in Table 2.

however, if our original patterns hold—and the accuracy seems to be good—the phenomenon is actual. It shows up in Wu and Soong's table, where they have computed the yearly increments in simple percentages of the previous value reached.) But the spurt is not great; and the general impression, what with the gentleness of the slopes during B-time, is natural to the casual observer that there is not any noteworthy change in speed-rate of growth in children at this age. This impression is inaccurate, none the less.

The adolescent velocity emphasizes what we already know. The female spurt is precocious over the male, carrying the girls to an absolute superiority in height at initial stages; a phenomenon well known to investigators of other portions of the human species. But the male in turn, on reaching puberty, shoots up phenomenally over the female, and he keeps at it longer.

Thus the entire male growth behavior, from birth to adulthood is somewhat more "jerky" than the female.

Had the velocity formula for the A-curve obtained always with no modification at $x = 20$, the female velocity would have equalled 22.5; the male, 17.06.

The figures for the AH-curve probably are inaccurate for the highest values of x. I have already pointed out that the lines for male and female had to be smoothed and flattened down in last adolescent years, because of the zigzag course of Wu and Soong's data in that period. Thus, probably the female velocity at $x = 18$ is actually less than 10.07 mm. But within limits, the values probably are accurate enough.

The slightly greater complexity of $\frac{d}{dx}$ (AH) for females than for males goes back, of course, to the fact that I have fitted for the males a formula in which R is a constant; in the females, R is the first derivative of a parabolic formula.

Actually, since the locus moves smoothly from the fit of one formula to the next, it is arbitrary to choose the exact spot where one formula leaves off and the next begins. The graphs are, in this trait, misleading, and allowance must be made.

E

Stature is a rectilinear dimension, usually recorded as equal numerically to a certain number of spatial units. For a growing child, a table of such recording may be accumulated over a period of years; and, of course, a parent, a physician, or the child himself, is interested in the changes so registered. Now the focus of interest is in the end-point of this growth process at any given moment. The fact that a certain altitude

has now been reached, is what usually interests the individual—not the *how* of achieving the point. Thus, when a graph of growth in stature is traced, as in our Figures 3 and 4, interest centers in the *ordinate* reading at any given moment.

But the student of a graph will see more than a severality of ordinates. Stature increase in time is a continuum. The continuum may be translated as the *locus* of *a* point. What, precisely, is that locus of a point?

The point is not a stature, since it is defined by both ordinate and abscissa. It is a stature-at-a-time. The locus of the point traces a space-time relationship: it is an *event*. Time is now a dimension.

It is important, I think, that this idea be clear. For it prepares us to ask of our graphs, What is the meaning of the *area* subtended by the locus of the point? and, What significance is there to the *length* of the locus?

First, the area.

If we compare the graphs of the two sexes (Figs. 3 and 4), or, if we were in the position to compare graphs of two races, clearly the areas under the loci would differ in size and shape. The differences would indicate that the two groups compared differed in height and in disposal of time-budget to achieve that height.

An animal that grows very rapidly in a given time, and achieves a height about equal to that of a slower-growing animal (suppose we were comparing man and chimpanzee), shows the steeper and shorter graph-line. The slope, of course, at any moment is given by $\frac{dy}{dx}$. But the *total-growth achievement-in-time* is given by the length of the entire line. Intrahuman comparison would be more or less striking, intergeneric comparison, say of man and chimpanzee, would certainly be very striking.

We thus are led to the concept of millimeter-years. It bears a spurious similarity to such units as the foot-pound, etc. of the physicist. The resemblance is more of an analogy than a similarity, for reasons which by now are rather obvious. For, while the ordinate measures the stature in millimeters at any moment, the area actually represents the behavior of a complex of growth-*forces* operating over time. Truly now we are viewing growth as an event, even while it has been registered on a graph in terms of a succession of statures at chosen moments.

So we have a given length of curve, and an area subtended by that length. The shape of the area, and also its size, are partially dependent upon the characteristics of that length of curve. We wish to indicate

some relationship. There are several possibilities. Not to overburden gratuitously a discussion already creaking under the load, let us fasten upon the simple expedient of dividing an area by the length of a side—the side being our curve.

We must calculate (1) the areas under the A, B, AH curves respectively; (2) the lengths of those curves; (3) we must divide the areas by the related curve lengths.

1. The area under a curve is given by the definite integral of its equation:

$$Area = \int_{x_1}^{x_2} y dx.$$

For the curves A and B, this is simply done:

For A: $\int (a + bx + .4343c \log_e x)dx = \int adx + \int bxdx$

$$+ \int .4343c \log x dx = ax + \frac{bx^2}{2} + .4343cx(\log_e x - 1) + C.$$

For B: $\int [k(a + bx + .4343c \log_e x) + q]dx$

$$= kax + \frac{kbx^2}{2} + .4343ckx(\log_e x - 1) + qx + C.$$

$$= x(ka + q) + \frac{kb^2x^2}{2} + .4343ckx(\log_c x - 1) + C.$$

However, $\int ve^{pB'^{\gamma}} dx$ offers grave difficulties.

It seems to me simpler, therefore, to reevaluate the AH-curve for an approximation that would be easier to handle. If we cut our curve

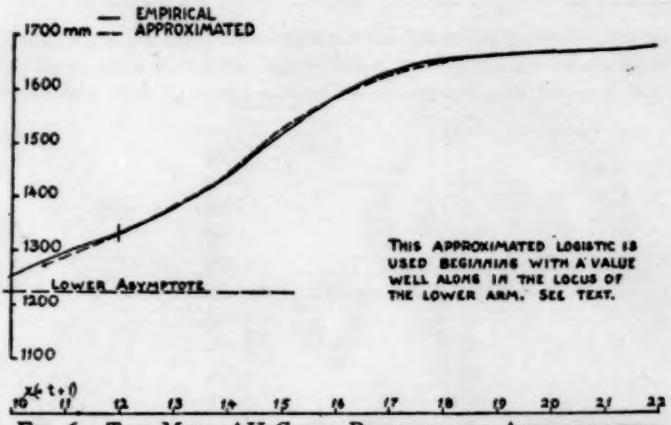

FIG. 6. THE MALE AH-CURVE RECALCULATED APPROXIMATELY

and initiate the AH portion at $x = 12$, $y = 1334$ (males; similarly, females), we find an incomplete logistic that is fairly symmetrical if projected and completed downward to a baseline at $\begin{cases} d = 1255 \\ d = 1204 \end{cases}$ (see Figs 6, 7). In our previous calculations, this would not have been admissible: we would have been embarassed to justify a logistic which took up suddenly and arbitrarily at the point we have now chosen. But there is nothing to prevent us from finding the approximate area from $x = 12$ to $x = 22$ for the definite integral

$$\int_{x_1}^{x_2} (y = \text{AH}) dx.$$

For males, this equals:

$$y = \frac{421}{1 + 1.1 \text{ antilog}_{10}(-.30675X)} + 1225,$$

where $X = x - 14$ or $x = X + 14$. We obtain:

x	y *emp.*	y *calc.*
12	1334	1331.4
13	1380	1385.4
14	1440	1440
15	1519	1528
16	1588	1587
17	1634	1627
18	1654	1650.5
19	1663	1663
20	(1670)[13]	1670
21	(1673)[13]	1673
22	1676	1676

[13] These are arbitrarily corrected values, substituted from the graph, for Wu and Soong's originals of 1664 and 1668, which would not lie on a smoothed curve. I felt justified in doing this because of the zigzag nature of their subadult values:

aet.	
17	1654
18	1663
19	1664
20	1668
21	1676
22	1676
23	1676
24	1683
25	1669
26 & +	1678

1676 was taken as an asymptote (see Fig. 3).

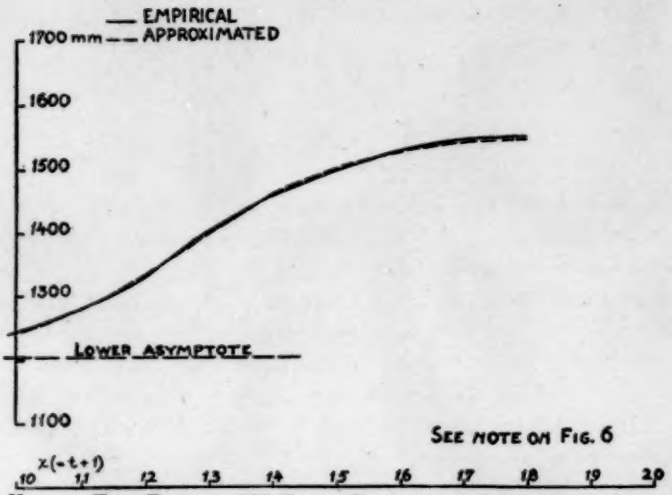

FIG. 7. THE FEMALE AH-CURVE RECALCULATED APPROXIMATELY

In like manner, the female approximate values for the AH-curve are:

	Observed from original graph (mm.)	*Calculated by new logistic formula (mm.)*
10	1246	1243.75
11	1280	1280.3
12	1330	1335.7
13	1406	1401.6
14	1460	1460.8
15	1497.5	1501.5
16	1527	1525
17	1544	1537
18	1548	1543

The approximate formula is:

$$y = \frac{344}{1 + .73924 \text{ antilog}_{10}(-.3383X)} + 1204,$$

where $X = x - 13$. These values are plotted, respectively, in Figs. 6 and 7.

The integral,[14] at long last, is:

$$\int_{x_1}^{x_2} [\mathrm{AH}]\, dx = \int_{x_1}^{x_2} \left(\frac{K}{1 + Ce^{rx}} + \delta \right) dx$$

$$= \frac{K}{r} \left[rx - \log_e(1 + Ce^{rx}) \right]_{x_1}^{x_2}$$

Now, when it comes to choosing the points for dividing up the entire system into the separate A-, B-, AH-areas, we run into the same difficulties we had when determining the graphs of velocities. At best, one can be only cannily arbitrary. After careful inspection, therefore, I have selected $x = 7$ or $t = 6$, in both sexes; and $x = 12$ or $t = 11$ in the female, $x = 13$ or $t = 12$ in the male; and have called a halt at $x = 19$ or $t = 18$ for the female, $x = 20$ or $t = 19$ for the male.

2. The length of an arc is given by an integral which includes the first derivative of the curve:

$$s = \int_{x_1}^{x_2} [1 + y'^2]^{\frac{1}{2}} dx.$$

The first derivatives are all available; so we have

for A:

$$s = \int_{x_1}^{x_2} \left[1 + \left(b + \frac{.4343c}{x} \right)^2 \right]^{\frac{1}{2}} dx;$$

for B:

$$s = \int_{x_1}^{x_2} \left[1 + k^2 \left(b + \frac{.4343c}{x} \right)^2 \right]^{\frac{1}{2}} dx;$$

for AH:

$$s = \int_{x_1}^{x_2} \left[1 + \left(\frac{-KCre^{rx}}{(1 + Ce^{rx})^2} \right)^2 \right]^{\frac{1}{2}} dx.$$

But these again are formidable cliffs to scale. If, instead, we use the trapezoidal rule,

$$s = (\tfrac{1}{2}y_0 + y_1 + \ldots\ldots + y_{n-1} + \tfrac{1}{2}y_n)\Delta x,$$

we obtain the approximations given in Table 7. (In every computation, $\Delta x = 1$.)

3. We now divide the areas by the lengths of arc for the final set of figures in Table 7.

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[14] I am indebted to Mr. H. H. Boschen, P.E., for obtaining this equation for me from Mr. G. J. Marianelli, M.E., whose disinterested kindness leaves me under obligation.

TABLE 7

Areas, curve lengths, and their ratios: Male and female

MALE			FEMALE		
I. Areas					
Arc segment	Total area under arc segment	Area generated by arc segment	Arc segment	Total area under arc segment	Area generated by arc segment
AH: $s\Big]_{18}^{20}$	11041.44	1406.44	AH: $s\Big]_{18}^{19}$	10415.6	1125.6
B: $s\Big]_{7}^{18}$	7440.56	930.56	B: $s\Big]_{7}^{18}$	6062.25	687.25
A: $s\Big]_{1}^{7}$	5270.80	2301.80	A: $s\Big]_{1}^{7}$	5184.6	2229.6
Grand total	23752.80	4638.80	Grand total	21662.45	4042.45
II. Curve lengths					
Arc segment	Length		Arc segment	Length	
AH: $s\Big]_{18}^{20}$	281.31		AH: $s\Big]_{18}^{19}$	154.76	
B: $s\Big]_{7}^{18}$	296.25		B: $s\Big]_{7}^{18}$	249.39	
A: $s\Big]_{1}^{7}$	612.88		A: $s\Big]_{1}^{7}$	602.17	
Totals	1190.44		Totals	1006.32	
III. Ratios					
Arc segment	Total area / Curve length	Generated area / Curve length	Arc segment	Total area / Curve length	Generated area / Curve length
AH	.....	5.00	AH	.....	7.28
B	.....	3.14	B	.....	2.755
A	.....	3.255	A	.....	3.706
Grand average	19.95		Grand average	21.53	

CRITICISM OF THE AREA-CONCEPT

When complete stature has been achieved, the line $y = f(x)$ becomes horizontal. It continues to preside over an area. But, from the standpoint of positive growth, the area has ceased to have meaning. That does not imply that it has become meaningless. Nevertheless, for our present purposes, it should be disregarded. But, even if we cut off the area at the point where the line finally becomes horizontal—where it practically coincides with the upper asymptote—the logistic curve is so graduated that much area is included under the line at the higher values of x, for very little addition in height.

Table 7 records the total areas under each segment of arc. But each such area is obviously a build-up from what has been achieved under the preceding segments or segments of arc, plus the additional area generated by the segment of arc next being considered. The grand total areas—23752.80 for males, 21662.45 for females—are useful in comparing with other populations or species; but the individual constituent blocks are not. On the other hand, the amount of area generated under each new and succeeding segment of arc, is a useful quantity. It is therefore a simple matter to subtract a rectangle from each total area, which rectangle represents the area for which the particular arc segment has not been responsible. From Tables 3 and 4, therefore, we read values of calculated y at the points where $x = 1$, $x = 7$, $x = 12$ (female), $x = 13$ (male), $x = 19$ (female), $x = 20$ (male); multiplying these values by the appropriate number of units on the x-scale, we obtain quantities to subtract from total areas, to give us the size of areas generated by each arc segment. The manner of obtaining the ratios should then be obvious. (See Table 7.)

The figures under "Ratios" give some indication of the slope or flare of the arc segment with reference to the area it generates. Thus, the male AH-curve flares much more than the female, as witnessed by Figs. 3 and 4; hence the ratio for males is 5.00, that for females is 7.28.

If the original graphs of the stature-curves be scanned with the figures of Table 7 in view, a curious aberration of proportion shows up, which a little reflection on the quirks of plane geometry will resolve. The graphs, although quite "natural" to the eye, are of course actually double-scaled; the abscissae being on a far larger scale than the ordinates.

Consequently, the different slopes of the curves disguise the true proportions of length between the A, the B, the AH-curves. Actually, we see from the table that the stature-time-point has traveled a locus which, for the A-curve, is over twice as long as either that of the B or AH curves. Also, in spite of the seemingly spectacular AH spurt, the length of the AH curve is even slightly shorter than that of the B curve—even though in the male, AH covers seven years and the B only 6.

SUMMARY OF PART ONE

In the parametric indices studied, growth accelerations occur at about the ages of first and second permanent molar completion; and growth practically ceases at the third-molar period. The female sex is precocious in initiating the second acceleration. The accelerations, as far as has been ascertained, are but a time-phenomenon; they speed up the process of growth, but they do not alter the growth pattern of bodily proportions. That pattern is already established at least as far back as birth. Without the first acceleration the "adult" proportions would have been reached, but at a later date.

The second, or adolescent acceleration, does not effect adult size any sooner than the prepubertal growth-pattern would have done; it only hastens it at first, then later, so retards that growth finally ceases. It is suggested that this is a primate, perhaps even a mammalian, distinctive trait.

But for this adolescent "dislocation" of the growth-pace, growth would seemingly be life-long; and the female, at first slightly the smaller, would eventually be clearly the larger. The adolescent reversal of this trend again may be a mammalian characteristic.

Formulae have been submitted that describe the growth-pattern very fairly. The formulae all are exponential types. Probably a more exact set of data would have shown the growth-pattern as a set of three logistics; at least the first two being very skew, and the first extending back to conception.

The velocities of growth are derivable from the growth-pattern formulae.

When a set of measurements are recorded on a graph of which one axis is that of time, infinite interpolation produces a continuum: the locus

of a traveling point. This is our curve of growth. Stature pictured as a curve, is now an event. The area under the curve is the value of a growth-in-time. The ratio of area to subtending curve is adopted as a sort of coefficient describing the relationship between them. It is thought that this concept will be useful in comparative growth studies where either time or somatic dimensions or both differ in the comparates.

MIGRATION AND URBANIZATION OF THE INDIANS IN CALIFORNIA

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I

THE racial assimilation of the American Indian is a problem of interest not only to the demographer and geneticist but also to the student of human ecology. The profound disturbance in environmental conditions to which the primitive race was subjected has been manifested in several aspects. One of these is the territorial redistribution of the aboriginal groups as a whole and another the dispersion of individuals in conformity with pressures exerted by white society. The latter phenomenon, which may be termed "internal migration" is here considered.

II

Over most of the United States the survivors of the Indian population have been restricted to reservations or otherwise subjected to artificial constraint. Hence any natural tendency to move about has been sharply inhibited. The State of California has, however, constituted an exception and has provided an opportunity to observe what an Indian group would do if left largely to its own initiative. The causes of this anomalous situation are clear. The first lies in the fact that the majority of California Indians were never reservationized but were left to merge as best they might with the American civilization which surrounded them.[1] The second factor lies in the peculiar manner

[1] Many early attempts to establish reservations (which at the time were literally concentration camps) were wholly unsuccessful. In the north there finally emerged the permanent establishments at Round Valley, Hupa Valley and Tule River which accommodated at most 2000-2500 persons. In the south the former Mission Indians and the Cahuilla were settled on numerous small areas contiguous with and surrounded by the general white population. The Yuma, on the Colorado River, were

in which the state was settled. From 1848 to 1860 the entire coastal region was suddenly overrun by whites who, to be sure, killed and starved large numbers of the natives but who left the survivors to persist in their ancestral habitat. The aborigines were thus submerged, rather than expelled or exterminated. The third factor was the very strong Spanish-Mexican tradition which persisted long after the American conquest. This tradition, strongly reinforced by the Catholic clergy, envisaged the Indian as an integral, even if subordinate, component of the social organism itself, rather than as an enemy to be segregated in isolation.

By virtue of another historical anomaly we come into possession of population data pertaining to the Indians of California which do not exist for any other state.

According to a treaty made by Wozencraft in 1851 compensation was to be paid the California natives. Not until 1928 did Congress act to carry out its terms, at which late date it had become necessary to determine who the descendants were. Congress then [2] authorized a census to be taken to list "all Indians who were residing in the State of California on July 1, 1852 and their descendants now living in said state".

This census was the most comprehensive and thorough that could be taken under the circumstances. For each individual it showed name, age, family relationship, degree of blood, tribal affiliation, residence and property owned. In all, 23,542 persons were recorded, and even if not absolutely complete, this record constituted the most thorough survey which could be secured.

With respect to coverage it is probable that practically all persons with an appreciable degree of Indian blood were counted. On the other hand it is likely that some individuals with very slight Indian blood who long since had come to regard themselves as wholly white were missed. With respect to correctness of statement there were undoubtedly errors introduced. Due to ignorance or design many persons were unable to state with utter fidelity degree of blood, age and tribal affiliation. Con-

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self-contained as a reservation tribe. In addition to the above, numerous Indians have been carried on the rolls of various agencies and have received government aid, although they were actually living on privately owned land scattered through the entire state. These, altogether, do not account for more than half the Indians in the region, the remainder never having been, in any sense, wards of the government.

[2] Act of May 18, 1928 (45 Stat. L., 602).

sidering the numbers involved, however, we may regard the general picture as correct in essence if not in minute detail. In certain instances particular items are left blank on the census sheets, due to admitted factual ignorance on the part of the persons involved. When compilations are made, therefore, these items cannot be included. As a result the totals for specific categories (such as age, degree of blood, residence, etc.) will always fall somewhat short of the general census total of 23,542. The sample, nevertheless, will usually be at least ninety per cent complete, thus rendering statistically insignificant the losses due to omissions.

The shift of individuals and hence groups may be determined by means of the present (1928) residence and the tribal descent.[3] Since the tribal boundaries were originally very definite and since there has been no mass movement during the past century it is possible to specify, for any individual a *home territory,* within which he or his ancestors must have lived. Although certain inexactitudes are thereby introduced it is most feasible to delimit former tribal areas along modern county lines. Thus the Yurok once inhabited parts of both Humboldt and Del Norte counties. For present purposes, accordingly, it is necessary to consider the entire area of both these counties as home territory. Any shift of residence within such a restricted field could not be considered a significant change of habitat. A second group may then be recognized: those who are living outside the home counties, or *migrants.* The data do not permit a more refined classification since the domicile of migrants varies progressively from fairly close to quite distant. Moreover, no deduction is usually possible with respect to whether it was the living person or his forebears who actually moved outside the aboriginal tribal boundaries. A third group may also be distinguished, including parts of the previous two: those who are living in *cities* rather than in villages or remote rural sections. The line of demarkation is based

[3] Tribal relationship is stated in the census with considerable exactness. Wherever possible the Indian Service used the newer nomenclature introduced by Kroeber and his colleagues. Thus the designations Yurok, Karok, Maidu, Pomo, etc. replace their older local equivalents. Some territorial terms still persist, such as "Smith River", "Eel River" or "Pit River" but these can usually be translated without difficulty into their ethnographic synonyms. In the south and on the coast reference is invariably to the former mission groups but since these people had lost their tribal identity prior to 1850 the use of missions is adequate to define the home territory in so far as American occupation is concerned.

upon the mailing address given under each name in the census which in numerous cases includes a street and number in some town or city. Now it may be assumed fairly that if a person has a street address in such a locality as Los Angeles, San Francisco, or even Stockton, Riverside or Eureka, he is a city dweller. Naturally this fails to include itinerants and other casuals with no established residence who might frequent the towns. On the other hand it errs on the side of conservatism and restricts the city class to *bona fide* urbanites.

III

The aboriginal distribution of population followed very closely that of the food supply. Today the situation has completely altered. Diet as a determining factor has been replaced by others, among which is the density of the white population. By virtue of war, disease and ineffectual economic competition the natives have tended to diminish most rapidly when and where the white men have been most numerous. This process reached its maximum intensity between 1848 and 1860 during which period the Indians of the mining regions were nearly obliterated. The long term influence of white settlement, moreover, can be detected in the census of 1928. By using counties as subdivisions the relation between the two races may be compared: the number of whites being taken directly from the United States Census of 1930 and that of the Indians being calculated from the 1928 census.

A direct test of association between absolute Indian and white population by counties yields a chi-square value of 2.19 which is below the limit of significance. If, however, we utilize the Indian home population (excluding migrants) the value is 5.86 which may be considered moderately although not strongly significant.

A better criterion of white influence than gross population per county is the density per county. The relation between this factor and the Indian population is expressed by a chi-square value of 11.79. Apparently, therefore, a tendency exists for the Indians to be most numerous in those regions where the whites are fewest.

As a final test we may employ the relative, rather than absolute Indian population, i.e. the ratio of Indians to whites, since this term is an index to the reaction of the Indians to the white group over a long period of years and also tends to eliminate extraneous geographical factors. The association between this ratio and density of the whites

is highly significant: chi-square equals 26.26. If the data are treated as a correlation the value of r is —.847, again definitely significant.

These results exemplify for California the generally recognized principle that an indigenous population thrives best over the period of transition in those regions where the density of the invading group, and hence the interracial conflict and competition, are at a minimum. The immediate response, therefore, to invasion by the foreign race, and one might say the fundamental inclination of the Indian population, was to remain as far out of contact with the whites as possible. Only thus could pure survival be achieved. However, with more settled conditions there has begun to appear the inevitable reaction and counter-trend toward intermixture. One criterion of its extent is the number of Indians who have voluntarily forsaken the home territory and have gone to dwell in a purely white community. In 1928 the census shows that 13.2 per cent of the California Indians were in this category.

One would conclude at first sight that the total migration among the Indian group had been relatively small up to 1928. The closest comparison is with the native born whites living in California at the same time. In 1930, 45.4 per cent of the latter had migrated from other states.[4] If intercounty, rather than interstate movements could be checked we should probably find that well over half the white people in 1930 were living some distance from the county of birth or parental origin.

On the other hand California is notorious for the unsettled character of its population, and the enormous number of new immigrants. The Indian value of 13.2 per cent removals might be considered more fairly in relation to that of more stable white groups such as the native born of Maine and South Carolina of which only 7.8 per cent were from outside the state. In brief, it is clear that the drift away from the ancestral habitat had definitely set in by 1928, and although it had not reached large dimensions, nevertheless was making headway against the basic inertia and conservatism of Indian tribal culture.[5]

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[4] *Fifteenth Census of the United States, 1930; Population*, Vol. II, p. 146.

[5] There are no statistical data concerning the matter, but much collateral evidence indicates that the migratory trend has much intensified since 1928. The depression of the 1930's and the acceleration due to the war have brought Indians from remote rural homes to the centers of agriculture and industry. Many of these will become permanent inhabitants of the new localities.

IV

We may now examine the conditions affecting migration, the direction of migration, and the character of the migrants. Certain factors may be distinguished which appear to have determined *the extent of migration*. These seem to have been chiefly historical, or long term influences, rather than contemporary effects, and to have been concerned with the degree of interracial contact.

The intensity of former conflict is discernible in the reduction of numbers since the American occupation. The aboriginal populations by tribes have been carefully worked out by Kroeber. I have made a fairly accurate estimate of the values[6] for the period 1845-1850. Finally there are the modern data in the 1928 census. When the per cent of modern survivors by tribes (from 1848) is related to the per cent of migrants from those tribes, the chi-square value is 8.71, in the sense that the smaller the per cent survivors the greater the proportion of these are migrants. Since the chi-square value is significant it is reasonable to conclude that serious depletion due to war and disease during the period of settlement operated to disintegrate tribal and geographic unity thereby rendering the subsequent generation more prone to seek new habitats. The extremes of this process may be noted in a qualitative manner by considering the Yana and the Luiseño, both tribes which were exposed to strong white influence. In modern times the Yana have been reduced to about 1 per cent of their former number (a few mixed bloods) all of whom live well outside the original tribal territory. The Luiseño, on the other hand, who still retain 45 per cent of their aboriginal strength show only 3.3 per cent migrants.

In conjunction with the factors governing emigration from the ancestral habitat one indirect line of evidence is the age distribution of the home and migrant groups. These distributions may be expressed graphically but perhaps the most convenient index, for purposes of comparison, is the median age.

It is a principle of universal applicability that whenever a free emigration occurs from a stable population the younger element predominates. Moreover the internal age dispersion is less owing to the reduced proportion of very old and very young persons. Following

[6] S. F. Cook, The Conflict Between the California Indian and White Civilization. Part III: The American Invasion, 1840-1870. Univ. Calif. Publ. Ibero-Americana. In Press.

resettlement the migrant group tends to reacquire the features of the parent stock. In the present instance the home population of 19,076 persons had a median age of 21.93 years with a standard deviation from the median of ± 23.1 years. Since the equivalent values for 2,973 migrants were 19.97 and 19.2, the latter group as a whole appears to be relatively recent in origin.

The designated differences in median age and age dispersion are, however, not sufficiently great to suggest a uniform and homogeneous migratory impulse within recent years. It appeared desirable, therefore, to break down the entire population into a series of component groups. On a basis of past history and geographical location there seems to be a more or less natural subdivision as follows:

I. Tribes, untouched by Ibero-American culture, exposed since 1850 to strong Anglo-American influence, north and central Cis-montane California: Tolowa, Yurok, Wiyot, Hupa, Karok, Chimariko, Wylackie, Yuki, Athabascan remnants, Pomo, Shasta, Maidu, Yana, Miwok, Wintun, Yokuts and Western Mono.

II. Tribes, untouched by Ibero-American culture, relatively isolated geographically from Anglo-American influence, trans-montane and desert California: Achomawi, Pauite, (including Eastern Mono and Tulatulabal) Washo, Shoshone (mainly Koso) and Yuma.

III. Tribes, ethnographically indistinct, which remain from the central coast missions as far south as Mission San Gabriel at Los Angeles, thoroughly impregnated with both Ibero- and Anglo-American cultures, since 1850 socially amalgamated with the surrounding white population.

IV. Tribes, ethnographically distinct, which remain from the south coast missions (San Luis Rey, San Juan Capistrano and San Diego plus the closely coterminous Cabuilla); differ from Group III in that they have been strongly under reservation influence and are socially somewhat isolated; considerably influenced by Ibero- and Anglo-American cultures but not so strongly as Group IV.

The pertinent data have been summarized in Table I. Certain features of this summary merit discussion. In the first place the median age of the geographically and politically isolated groups (II and IV) is high, that of the intermediate group (I) is medium and that of the well assimilated group (III) is low. At the same time the per cent of each group which has migrated varies in the opposite direction.

The median age of the migrants is lowest for Group II and also

TABLE 1

Per cent migrants and median ages in four Indian groups

	PER CENT MIGRANTS	MEDIAN AGE HOME GROUP	MEDIAN AGE MIGRANTS	MEDIAN AGE CITY DWELLERS
Group I.....	15.4	21.26	20.18	18.26
Group II.....	6.3	23.13	19.58	17.83
Group III	40.1	19.65	19.62	19.00
Group IV	6.5	23.64	20.50	20.32

differs by the greatest amount from that of the non-migrants. Nearly the same situation exists for Group IV. According to the thesis mentioned above the inference may be advanced that the migration from these two groups is of relatively recent origin, an hypothesis supported by our general knowledge of the peoples concerned. Group I again occupies an intermediate position implying that migration has been proceeding for a longer period. This is in conformity with the fact that during the latter half of the nineteenth century the northern and central tribes were subjected to severe dislocation by the invading miners and ranchers as well as by the armed forces. Group III shows no significant difference whatever in the median age of migrants and non-migrants. This may be taken as reflecting the turmoil and disintegration of the post-mission period, 1830-1850, and the disappearance of the mission Indians as a distinct social entity. The transition stage, however, has completely passed such that both components of the group have reached a new and probably stable equilibrium.

From the above findings we may conclude that whenever the native race, in California, has entered upon a period of intensified contact with the whites, there has been a response in the form of increased emigration, primarily on the part of the younger individuals.[7] This response is by no means inconsistent with that previously discussed whereby the population subjected to intense conflict suffered more

[7] During the past twenty-five years the automobile has exercised a tremendous influence on the mobility of the California Indian. Previously it was very difficult, in the purely physical sense, for him to leave home. More recently, however, he has become accustomed to travel hundreds of miles with little effort. As a result his spatial horizon is widening.

extensive loss in numbers than that which was permitted to remain in comparative isolation. Indeed, the two reactions are component parts of the same mass behavior pattern.

V

The *direction of migration* has been uniformly toward the centers of white population with the result that an Indian urban class has come into existence. To support this conclusion are various lines of evidence.

a. In any given county the relative number of Indian immigrants may be expressed as the ratio between immigrants and total Indians. This value may then be related to the density of white population. For the 58 counties the association by chi-square is 8.48 and the correlation coefficient, r, is $+ .541$. There is a significant movement, therefore, toward regions of high population density.[8]

b. The Indians as a whole tend to follow the degree of urbanization characteristic of the region. Thus there is a significant correlation ($r = .676$) between the ratio of Indians in cities to total Indians on the one hand, and the ratio of whites in cities to total whites on the other. That the phenomenon has reached considerable dimensions is attested by the fact that eleven per cent of the names recorded in the 1928 census had street addresses and were therefore definitely urbanized. Predominantly migrants have contributed to this group, for of the non-migrants throughout the state 7.43 per cent were in cities, and of the migrants, 40.1 per cent. There can be no doubt, consequently, that urbanization is a process closely associated with migration.

c. The median ages of city dwellers (see Table 1) throws further light on the situation. With Group I the median age of the urban component is definitely below that of the migrants. It is probable that this represents a secondary, more modern movement, for the earlier migrants were relatively primitive and perferred to remain in rural communities. With Group II the city dwellers appear to represent what might be called the progressive younger element, those migrants who went all the way to the larger centers of population, rather than

[8] These indices would show an even greater level of significance were it not for Del Norte, Humboldt and Trinity Counties which, although sparsely inhabited, contain many Indian immigrants. The reason for these exceptions is that seventy-five years ago, through forced removal and warfare, the northwestern tribes were extensively redistributed within the territory at large.

remain in more remote districts. Group IV shows an urban median age almost identical with that of the migrants, both being definitely below that of the non-migrants. As contrasted with the mountain and desert tribes of Group II, when the Indians of Group IV left home, they had in effect no place to go save the Los Angeles metropolitan area, and as a result this region has absorbed most of them. With Group III the urban median age is a little but not materially, below that of the migrants, due probably to a slight tendency in recent years for the younger people to gravitate to the nearby towns.

VI

Something concerning the *type of people* who make up the migrant and urban classes can be deduced from the census. It has already been pointed out that in the aggregate, with certain exceptions, they are more youthful than those who still remain in the old tribal habitat. An examination by sexes shows the male-female ratio to be highest for the home dwellers (1.072), lower for migrants (0.890) and least for the urban class (0.798). For the total population the ratio is rather high: 1.045. A heavier migration by woman, than by men, is thus indicated. From a breakdown of sex ratios by age (see Table 2) it is apparent that among migrants and urbanites the great predominance

TABLE 2

Sex ratios by age group

AGE IN YEARS	0-9	10-19	20-39	40-99	TOTAL
Home	1.031	1.055	1.134	1.060	1.072
Migrants	1.114	0.915	0.756	0.827	0.890
Cities	1.117	1.036	0.586	0.582	0.798
Total	1.042	1.035	1.008	1.032	1.045

of women is among those of early maturity and middle age. There are two factors which appear to be largely responsible for this phenomenon: (1) Many Indian women have married men of other races who have gone to the centers of agriculture and industry, whereas very few Indian men have married outside their own race; (2) numerous other

Indian women and young girls have in the past gone to accept employment as domestic servants in white families. Such individuals have been likely to marry or otherwise permanently sever all ties with the ancestral home. The result has been a steady drain upon the females in the home localities. That this process is of no very recent origin is attested by the low sex ratio among the migrants over forty years of age.

If the socio-geographic groups discussed previously (see Table 1) are examined the trend toward female predominance is found to be least in Group III (ratio for all ages of migrants is 1.092) and greatest in Group II (corresponding ratio is 0.717). This is in conformity with the fact that Group III has been in longest and closest contact with American civilization whereas Group II has been left in maximum isolation.

Another characteristic of migrants and urbanites is their consistently lower degree of Indian blood.[9] The mean values for per cent Indian blood are, for the entire state: non-migrants 68.3, migrants 40.7, city dwellers 36.9. This is true even in the highly assimilated Group III where the per cent Indian blood among non-migrants is 50.9 and among migrants is 29.7. Among the individual tribes it is possible to compare mean degree of Indian blood (per tribe) and per cent of migrants. We obtain a value for chi-square of 13.34 and for the correlation coefficient, *r*, of —.768, both indicating a very significant relationship. There is thus a consistent tendency for individuals and groups genetically farthest removed from the pure Indian strain to migrate to centers of white culture. The social and racial motivation of this trend is obvious and needs no comment.

In addition to age, sex and degree of blood we can derive certain information from the 1928 census pertaining to the family relationship of migrants and urban population. The census undertakes to set forth the exact family status of each person—such as husband, wife, widow, son, daughter, father, mother, cousin, single, etc. However, the relationships are social, rather than genetic. Thus there must invariably be a *head,* whether that individual is husband, widower, wife, widow, sister, brother, or unmarried mother. The remaining members of the social

[9] In the census, degree of Indian blood is expressed as a common fraction, i.e. ½, ¼, etc. To avoid this awkward notation the fractions are here converted into terms of percentage, where the per cent designated always refers to proportion of Indian, not white, blood.

family unit are grouped around the head. As a result, mature men and women frequently are listed as sons or daughters, while children occasionally appear as single or even as head of the family. The term *single* is reserved strictly for persons who are living apart from any recognized social family, although it may be obvious from the names that they have numerous relatives in the vicinity. For present purposes it has seemed advisable to set up four main categories which are of clearer connotation than the minor subdivisions:

1. *Head:* includes husband, wife, widower, widow, divorcée or illegitimate parent.
2. *Child:* includes all progeny of a head who are actually living under the same roof as the latter.
3. *Other relatives:* includes parents, aunts, uncles, nieces, grandchildren, etc. who are living with the designated head.
4. *Single:* includes any individual living apart from a recognized family unit.

TABLE 3

A

Family relationships in per cent of total, including both sexes

	HEAD	CHILD	OTHER RELATIVES	SINGLE
Home	40.9	48.1	2.9	8.0
Migrant	40.4	49.2	2.3	7.9
Urban	38.3	50.9	2.6	8.0

B

*Sex ratios for the classification shown above**

	HEAD	CHILD	OTHER RELATIVES	SINGLE
Home	.774	1.182	...	2.886
Migrant	.475	1.187	...	1.950
Urban	.402	1.190	...	1.164

* The ratios of other relatives were not calculated since their number is very small, and their significance doubtful.

For the state as a whole the distribution of these categories is shown in Table 3A. It will be observed that the general constitution of the family, *irrespective of sex,* is nearly identical in the home, migrant, and urban groups. If, however, we segregate the categories according to sex certain deviations appear. In Table 3B, it is shown that whereas the male-female ratio for children is almost identical for all three classes, the ratio for heads and single persons is markedly lower among the migrants and still lower among the urban class. In other words, wives predominate over husbands, and the relative number of single women becomes larger as the Indians move away from the primitive locality, or go to the cities. This result intensifies the previous impression derived from the age distribution of sex ratios that a greater number of females than males move into regions of high population density.

VII

The broad outline of migrational shift among the present Indian population in California now seems fairly clear. Beginning gradually to overcome a fundamental inertia developed during generations of strict localization these natives are showing a tendency to move out from their primitive habitats such that by 1928 some thirteen per cent of their population were emigrants. This movement has been intensified whenever and wherever contact with the whites was brought to a high level of intensity. On the whole its direction has been toward rather than away from the regions of most dense American settlement. The active participants have been and still are predominantly persons in late youth or early middle age, with a considerable admixture of white blood. A large share of them have been females who have entered white society by the pathways of matrimony or economic employment. This process appears to have accelerated in recent years and probably will run to completion within a few generations.

HANDEDNESS AND DERMATOGLYPHICS IN TWINS*

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TWINS, both identical and fraternal, are characterized by a high percentage of left-handers, as contrasted with the single-born. About 20 percent of both types of twins show intra-pair differences in handedness (Rife, 1939), whereas only 13 percent of randomly paired sibs shows such intra-pair variation. Various theories have been proposed to account for the higher frequency of left-handedness in twins.

Newman (1937) believes the intra-pair differences in handedness are due to the operation of an asymmetry mechanism. Those twins arising from embryos which separated before the primordia of handedness were established would have the same handedness, whereas those embryos which did not separate until after the establishment of the primordia of handedness show intra-pair differences. The high frequency of left-handedness in twins is thus ascribed to an asymmetry mechanism, which would not be functional in the determination of handedness in the single-born. The obvious shortcoming of Newman's hypothesis is that it completely fails to account for the excess of left-handers in fraternal twins.

Verschuer (1932) believes the intra-pair differences in handedness in both types of twins to be due to conditions *in utero,* peculiar to twins. He points out that the ratio of pairs consisting of two right-handers, a right- and a left-hander and of two left-handers does not deviate significantly from what one should expect on a chance basis. While this hypothesis accounts for the high frequency of left handedness in both types of twins, it does not appear to be a complete explanation, as there is convincing evidence from other sources that handedness in the single born has a genetic basis. For example, when both parents

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are left-handed about 50 percent of the children are left-handed, if one parent is left-handed about 17 percent of the children are left-handed, and if both parents are right-handed about 6 percent of the children are left-handed (Chanberlain, 1928; Rife, 1940).

The writer has observed that twins showing intra-pair differences in handedness are likely to have left handers among their immediate relatives. An investigation (Rife, 1939) of 305 sets of twins and their families showed that in both types of twins those pairs showing intra-pair differences in handedness are about twice as likely to have left-handers among their immediate relatives as are those pairs consisting of two right-handers. These findings led the author to suggest that the high frequency of left-handedness in both types of twins may be due to the fact that those pairs genotypically intermediate in handedness, consist of one right-hander and one left-hander, the unusual position *in utero* being sufficient to influence the expression of functional handedness. Those pairs genotypically strongly predisposed to either right or left-handedness, would not be influenced by position *in utero,* and would show no intra-pair differences.

The work of various investigators has demonstrated that an association exists between dermatoglyphics and functional handedness (Bettman, 1932; Newman, 1934; Leche, 1933; Cummins, 1940; Cromwell and Rife, 1942). Comparisons of the dermatoglyphics of twins, classed as to handedness, affords an excellent means for checking the validity of our hypothesis concerning the cause of the higher incidence of left-handedness in twins. If correct, the dermatoglyphics of two right-handers should differ from twins differing in handedness or consisting of two left-handers in somewhat the same manner as right-handers differ from those of left-handers among single-born.

The system employed by Cromwell and Rife (1942) affords an unusually good method for such a comparison. According to this system, for each of the pattern areas under consideration, the numbers of individuals having a pattern on right hands only and on left hands only are recorded. The five pattern areas characterized by the greatest bimanual variation in the general population are those considered. These are the thenar, second, third and fourth interdigital areas of the palm and the ring finger. In the ring finger the criterion is the presence or absence of a whorl, rather than the presence or absence of a pattern of any type. For each area the hand characterized by greatest pattern frequency in the general population is termed superior, whereas the other

TABLE 1

The distribution of superior and inferior patterns among the single born and twins

R—right-handed; L—left-handed; I—identical twins; F—fraternal twins; S—single born: T—thenar/first interdigital; II—second interdigital area; III—third interdigital area; IV—fourth interdigital area; R—ring finger.

TYPES OF INDIVIDUALS	NO. INDIVIDUALS OR PAIRS		T	II	III	IV	R	TOTAL *No.*	TOTAL *Percent*
R S	♂ 300	S	26	17	104	81	60	288	19.4
		I	1	5	14	29	11	60	4.0
L S	♂ 418	S	44	27	124	98	73	366	17.2
		I	3	9	23	40	22	97	4.6
R S	♀ 300	S	14	11	83	71	46	225	15.1
		I	5	4	16	21	16	62	4.1
L S	♀ 322	S	14	7	101	68	45	235	14.5
		I	9	10	22	32	22	95	5.9
R-R I	♀ 96	S	22	11	56	36	27	152	15.8
		I	5	0	7	13	10	35	3.6
R-L I	♀ 36	S	3	0	14	12	2	31	8.6
		I	0	0	5	5	8	18	5.0
L-L I	♀ 5	S	0	0	2	4	4	5	10.0
		I	0	0	0	1	3	4	8.0
R-R I	♂ 66	S	11	6	42	28	23	110	16.6
		I	0	0	9	4	2	15	2.2
R-L I	♂ 20	S	7	1	11	11	8	38	19.0
		I	0	0	1	2	1	4	2.0
L-L I	♂ 4	S	3	2	3	3	4	15	37.5
		I	0	0	0	0	0	0	0.0
R-R F	♀ 50	S	4	5	36	11	11	67	13.4
		I	1	0	6	9	7	23	4.6
R-L F	♀ 11	S	0	1	3	0	2	6	5.4
		I	1	0	4	2	2	9	8.1
R-R F	♂ 29	S	4	6	15	9	8	42	14.5
		I	0	0	2	3	2	7	2.4
R-L F	♂ 6	S	1	1	4	0	1	7	11.6
		I	0	0	1	3	1	5	8.3
R-R F	♂♀ 29	S	6	2	15	12	7	42	14.5
		I	1	0	2	4	1	6	2.0
R-L F	♂♀ 10	S	1	2	5	2	8	18	18.0
		I	0	1	1	2	0	4	4.0
L-L F	♂♀ 3	S	0	0	2	2	0	4	13.3
		I	0	0	2	0	0	2	6.6

hand is termed inferior. The right hand is superior for the ring finger, and the second and third interdigital areas, while the left hand is superior in the thenar/first interdigital, and fourth interdigital areas. In the general population, left-handed females show significantly greater proportions of individuals having patterns only on inferior areas than do right-handed females. While similar trends are shown in males, they are much less pronounced, and are of no statistical significance (Cromwell and Rife, 1942).

As a pair of twins possesses two right and two left hands, the above system requires some modification in comparisons of their dermatoglyphics. Thus, if a pair of twins has whorls on both right ring fingers, and none on either of the left ring fingers, the pair is recorded as having two superior ring finger patterns. If one right ring finger and one left ring finger of the pair have whorls, or if all four ring fingers possess whorl patterns, or if none possesses a whorl, the inferior and superior values cancel for that particular pair. If a pair has whorls on two rights and one left ring finger, or on one right and neither left, the pair has a superior value of one for that area. Likewise, if a pair has whorls on both left ring fingers and one right, or on one left, and on neither right, the pair has an inferior value of one for that area. In other words, only the excess of patterns in superior or in inferior areas within pairs is recorded.

Table 1 shows such comparisons for 365 pairs of twins, grouped according to zygosity, sex and handedness. Data from 1340 single-born individuals (Cromwell and Rife, 1942) are also included. The criteria for handedness are the same as those used by Cromwell and Rife (1942). The twins were diagnosed as to zygosity on the basis of criteria described elsewhere (Gardner and Rife, 1942). Note that among the females of both monozygotic and dizygotic twins those pairs consisting of two right-handers show considerably greater bimanual variation than do those having one or two left-handers. Male fraternals, as well as unlike-sexed fraternals, likewise show a decrease in superior-inferior variation in pairs having one or two left-handers. This trend is reversed in male identicals, but only twenty such pairs differing in handedness are included.

Figure 1 illustrates the percentages of inferior and superior patterns among the single-born groups investigated by Cromwell and Rife (1942), and among the 365 pairs of twins included in this investigation. As five pattern areas are considered on each hand, the total number of

paired pattern areas within the single born is five times the number of individuals, and within twins ten times the number of pairs of twins. An examination of Fig. 1 reveals similar trends for the single-born

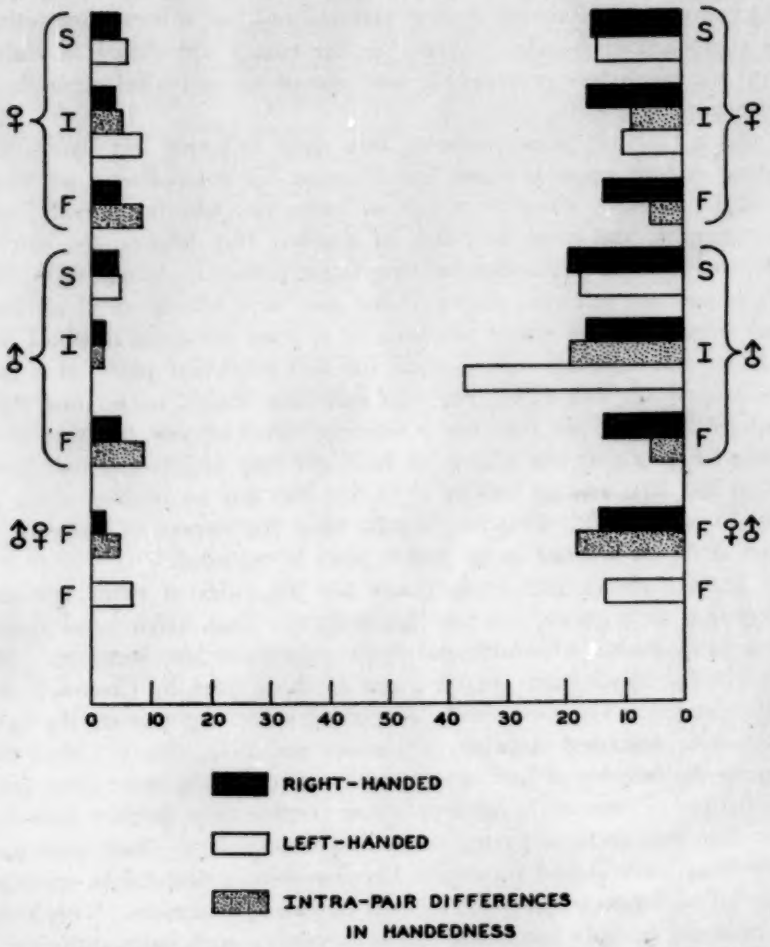

FIG. 1. DIAGRAMMATIC REPRESENTATION OF PERCENTAGES OF SUPERIOR AND INFERIOR PATTERNS WITHIN BOTH SINGLE BORN AND TWINS, GROUPED ACCORDING TO SEX, ZYGOSITY AND HANDEDNESS

Inferior percentages are shown in column on left and superior percentages in column on right. For actual percentages see Table I. S-single born; I-identical twins; F-fraternal twins.

and twins of both types. Especially striking is the increase among females of inferior patterns in both the left-handed single born and in both R-L and L-L twins as contrasted with the right-handed single-born and R-R twins.

A slight increase is shown in the occurrence of inferior patterns among left-handed single-born males, but there is a slight decrease among R-L and L-L identical male twins. Male and unlike-sexed fraternal show slight increases in the frequencies of inferior patterns in R-L as contrasted with R-R pairs, but these groups are small.

TABLE 2

Comparative frequencies of inferior patterns among female single born and twins, grouped according to handedness

Chi-square values of 3.841 or above are considered significant.

TYPES OF INDIVIDUALS	NO. PAIRED PATTERN AREAS WITHOUT INFERIOR PATTERNS	NO. INFERIOR PATTERNS	TOTAL NUMBER PAIRED PATTERN AREAS	X^2
Right-handed single born females	1426	62	1488	4.55
Left-handed single born females	1516	95	1611	
Right-handed pairs female twins	1402	58	1460	3.55
Female pairs twins one or both members left-handed.....	489	31	520	
Right-handed female single born plus twins.....	2828	120	2948	11.3
Left-handed single born plus twins with one or both left-handed	2005	126	2131	

Table 2 shows the results of comparisons in 2 x 2 tables of the frequencies of inferior patterns among females grouped according to handedness. Among the single born the occurrence of inferior patterns is significantly higher in left-handers than in right-handers. Among twins, identicals and fraternals combined, the frequence of inferior patterns is greater among pairs having one or two left-handers, the increase being slightly below the level of significance. When twins and single born are combined, the differences are highly significant. As males show only slight, and not completely consistent, differences in

the frequencies of inferior patterns between groups differing in handedness, a statistical comparison is not necessary.

These observations confirm what should be expected if R-L twins are genotypically more predisposed towards left-handedness than are those pairs composed of two right-handers. But it may logically be argued that the expression of *both* handedness and dermatoglyphics in twins can be modified in those pairs which separate relatively late by the operation of the asymmetry mechanism. If correct, however, we should expect the dermatoglyphics of the right-handers within R-L identical twin pairs, especially among females, to show lower frequencies of inferior patterns than do the left-handed members of such pairs. If our genotypic hypothesis is correct, no such intra-pair differences should be manifested.

TABLE 3

Comparisons of superior and inferior pattern frequencies of right-handers with left-handers from R-L identical twins

TYPES OF INDIVIDUALS	NUMBER INDIVIDUALS		T	II	III	IV	R	TOTAL	RATIO S-I
R from R-L♀ I	36	S	2	0	8	6	2	18	1.6:1
		I	0	0	3	3	5	11	
L from R-L♀ I	36	S	1	0	6	6	3	13	1.8:1
		I	0	0	2	2	3	7	
R from R-L♂ I	20	S	2	1	5	5	2	15	7.5:1
		I	0	0	1	0	1	2	
L from R-L♂ I	20	S	5	0	6	6	6	23	11.5:1
		I	0	0	0	2	0	2	

Table 3 shows comparisons of the right-handers with the left-handers of 36 female and 20 male identical R-L pairs, in respect to the occurrence of superior and inferior paired pattern areas. No real differences are indicated between right and left-handers, the right-handers showing slightly more inferior patterns than the left-handers.

The evidence obtained from dermatoglyphics thus agrees with that obtained from investigations of the handedness of the relatives of twins, in strongly indicating that whether or not a given pair of twins shows intra-pair differences in handedness depends upon the genotype of the twins.

SUMMARY

Left-handed single born individuals show significantly higher frequencies of inferior patterns than do right-handed single born. This tendency is significant only in females.

Female twins, both identical and fraternal, manifesting intra-pair differences in handedness, or consisting of two left-handers, show increases in the occurrence of inferior patterns when contrasted with those pairs consisting of two right-handers. Similar trends are not apparent in male twins.

No differences are apparent in the occurrence of inferior patterns between right and left-handed members of identical twin pairs, showing intra-pair differences in functional handedness.

Intra-pair differences in handedness in identical, and to some extent in fraternal twins, apparently occur in those pairs genotypically intermediate in respect to functional handedness. Circumstances *in utero* modify the expression of the trait in that members of the pair differ. Twins genotypically strongly right or left handed show no intra-pair differences in handedness.

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DERMATOGLYPHICS AND "MIRROR IMAGING"

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THE manifestations of bilaterally asymmetrical features in pairs of identical twins have been the object of much interest and speculation. Handedness, the hair whorl at the vertex, and dermatoglyphics have attracted particular attention. Since identical twins are so closely similar in other respects, intra-pair differences in asymmetrical traits such as these have been specially emphasized. The existence of comparable differences in fraternal twins and in randomly paired sibs has been largely overshadowed, resulting in a rather widespread but mistaken impression that asymmetry reversals occur in most identical twin pairs and that they are evidence of monozygosity (Kaomai, 1928).

Intra-pair reversals of bilaterally asymmetrical traits are frequently called "mirror-images". Although many traits show occasional mirror-imaging in twins, in all probability, pairs never are complete mirror-images of each other. The members of such a pair would necessarily differ internally, in that one member would have a complete transposition of the viscera (*situ inversus viscerum perfectus*); they would present also complete reversals in such traits as handedness, eye dominance, hair whorl, dermatoglyphics, dental irregularities and pecularities of ear form. Only a few pairs of monozygotic twins have been recorded as showing *situ inversus viscerum* in one member of the pair, and it is extremely doubtful that the visceral transposition in these cases is traceable to the state of twinning. Reversals of visceral asymmetry, handedness, hair whorl and dermatoglyphics appear to occur independently of each other.

About 20 percent of both identical and fraternal twins show intra-pair differences in functional handedness, as contrasted with only 13

percent of randomly paired sibs (Rife, 1940). As both types of twins show a higher incidence of left-handedness than the single-born, handedness is obviously of no value in twin diagnosis. Recent investigations (Rife, 1940) indicate that whether a pair of twins is alike or unlike in handedness depends upon their genotypes, rather than upon a hypothetical asymmetry mechanism which is subject to reversals of action in monozygotic twinning (Newman, 1940). Twins strongly predisposed by genotype to right or left handedness show no intra-pair differences, while circumstances peculiar to twins *in utero* may result in intra-pair differences in twins that are genotypically intermediate or ambidextrous.

In this paper we are primarily concerned with asymmetry reversals or so-called mirror-imaging of dermatoglyphics, especially in twins. In the general population most dermatoglyphic features show bimanual distinctions of frequency, some having greater frequencies on right hands, and others on left hands. Is there a tendency among identical twins for one member of the pair to show reversals of the usual bimanual differences, with consequent resemblance of the right hand of one member to the left hand of the other member? Newman (1928) has stated: "In every pair of obviously monozygotic twins, the rule holds, that there is stronger cross resemblance between the hands of one twin and those of the other, than between the two hands of the same individual." Such cross resemblances might be between the two right and the two left hands of the pair, or between the right of one and the left of the other. The latter type of resemblance would be what is usually classed as mirror-imaging, or heterolateral similarity. Often it has been inferred from such statements that heterolateral resemblances in identical twins are as common as are homolateral resemblances (right with right and left with left).

Investigators of twins generally agree in recognizing dermatoglyphics as valuable, although not infallible, criteria of zygosity (Cummins, 1930; MacArthur, 1938). It is logical to suppose that identical twins should show great homolateral resemblances, in view of the fact that they have the same genotypes, and that there are bimanual variations in the occurrence of patterns. The bilateral similarities of each member of the pair should be of about the same order as the heterolateral similarities of the two members, and less than their homolateral similarities. If there were an asymmetry mechanism operating in the production of identical twins in such a way as to cause frequent asymmetry reversals, a disproportionally high heterolateral resemblance might be expected in identical twins.

Meyer-Heydenhagen—method and data

It is possible to predict how frequently asymmetry reversals or "mirror-imaging" should occur on the basis of pure chance.

If we allow:

a = percent individuals with patterns on both hands
b = percent individuals with patterns on right hands only
c = percent individuals with patterns on left hands only
d = percent individuals with patterns on neither hand.

Then:

$a + b + c + d$ = 100 percent
$(a + b + c + d)^2$ = frequencies of various combinations with pairs
$2bc$ = expected frequency of pairs showing mirror-imaging.

This type of calculation was first employed by Meyer-Heydenhagen (1934). She compared the observed and calculated frequencies of $2bc$ in 100 pairs of identical twins and 100 pairs of fraternal twins. Four features were included, the terminations of lines D and A, and the occurrence of thenar and hypothenar patterns. Her data show that there are no significant deviations of observed from expected values, and the frequencies of $2bc$ are of practically the same order in both types of twins.

Lauterbach data

In 1924 Lauterbach conducted an investigation of over 200 pairs of twins attending the high schools of four Wisconsin cities (Lauterbach, 1925). Later he generously placed at the disposal of the junior author his extensive data, including palm prints for each pair, records of numerous other physical traits, intelligence quotients, photographs and a notation of his judgement as to zygosity.

Table 1 lists the frequencies, in percentages, of instances of dissimilarity of palmar features in twin pairs (65 identical pairs, 118 fraternals). The comparisons are drawn in the three possible ways: bilateral, comparing opposite hands in the same individual; homolateral, comparing corresponding hands in the two members of the pair; heterolateral, comparing right hand of one twin with the left hand of the other. In the case of the five configurational areas listed first in the table the comparison is based on the presence or absence of true

TABLE 1

Per cent of pairs showing dissimilarity in identical and fraternal twins (Lauterbach series)

	TYPE OF COMPARISON	IDENTICAL TWINS (65 pairs)			FRATERNAL TWINS (118 pairs)		
		Bilateral	Homo-lateral	Hetero-lateral	Bilateral	Homo-lateral	Hetero-lateral
QUALITATIVE FEATURES	Hypothenar	32.3	27.7	30.0	30.9	45.3	45.8
	Thenar-1st interdigital	12.3	13.1	15.4	15.7	20.3	19.1
	Second interdigital	5.4	5.4	6.2	8.1	13.1	14.4
	Third interdigital	43.1	29.2	46.9	39.0	53.4	55.1
	Fourth Interdigital	41.5	37.7	46.9	43.6	57.2	57.2
	Total average	26.9 ± 3.8	22.6 ± 3.6	29.0 ± 3.9	27.6 ± 2.9	37.9 ± 3.1	38.4 ± 3.1
	Line C	26.9	21.5	27.7	17.8	20.8	20.3
QUANTITATIVE FEATURES	a-d distance	29.8	38.7	45.8	35.9	57.4	64.9
	Line D	66.9	63.7	67.7	68.8	78.0	75.0
	a-b	25.0	32.2	26.6	24.1	43.4	42.9
	b-c	18.5	19.3	17.7	14.9	38.2	39.0
	Total average	35.0 ± 4.2	38.4 ± 4.3	39.4 ± 4.0	35.7 ± 3.1	53.4 ± 3.1	55.4 ± 3.2

patterns, and does not extend to the various types of patterned configurations. Line C is considered in reference to the presence or absence of any one of the expressions or reduction of the line (in formula, *O*, *X* or *x*). Each of the quantitative comparisons involves the measured distance between two triradii; in all the individual comparisons the two distances were recorded as dissimilar only if the difference in the two measurements exceeded 2 mm.

TABLE 2

The frequencies of pairs of identical twins from the Lauterbach series showing mirror-imaging in palmar dermatoglyphics, as compared with 2bc values obtained from 200 unrelated individuals

	SINGLE-BORN INDIVIDUALS	IDENTICAL TWINS
Hypothenar	.033	.015
Thenar-first interdigital	.007	.015
Second interdigital	.001	.000
Third interdigital	.056	.015
Fourth interdigital	.062	.075
a-d	.025	.080
Line D	.170	.190
a-b	.020	.064
b-c	.017	.048
Mean	.049 ± .015	.062 ± .031
Difference = .013 ± .034		

Table 2 shows the observed frequencies of intra-pair reversals in 65 assumedly monozygotic twins included in the Lauterbach series. *2bc* values in this instance were determined from *a*, *b*, *c*, and *d* values including 200 unrelated single-born individuals unselected for handedness, 100 males and 100 females. Nine different features, including each of the five palmar pattern areas, intertriradial distances a-d, a-b, b-c, and the radial extent of main line D were used in these comparisons. In no case is there a significant deviation between values for the unre-

lated single-born and for identical twins; the difference between the means is less than one-half of the probable error.

Recent data

A similar method has been used in the analysis of the prints of twins, paired sibs and unrelated pairs assembled by the senior author. These latter data were obtained from 227 pairs of identical twins, 96 pairs of liked-sexed fraternal twins, 296 paired sibs and 1,306 unrelated individuals. As shown in Tables 4 and 5 males and females were treated separately.

The twin data were collected at the International Twin Conventions at Fort Wayne in 1937 and 1939, and the Maine Twin Party in 1938, the Baylor University Twin Club parties in 1940 and 1941, and from twins attending the Public Schools of Columbus and Ohio State University and living in or around Columbus. The excess of identical twins is largely due to the fact that far more identical than fraternal twins attend twin conventions and parties.

Diagnosis was made on the basis of general similarities in physiognomy, body conformation and dermatoglyphics. Whenever feasible the blood groups and M and N reactions were obtained. As

TABLE 3

Observed and calculated numbers of assumedly identical and fraternal twins alike in the blood groups and reactions, and unlike in one or both. The calculated numbers for fraternal twins are derived from the percentages of like and unlike pairs found among single-born brothers and sisters

	ASSUMEDLY IDENTICAL TWINS		ASSUMEDLY FRATERNAL TWINS	
	Observed	Calculated	Observed	Calculated
Alike.....	145	145	42	36.2
Unlike.....	0	0	51	56.8
			X^2 of difference = 0.75	

shown in Table 3, all twins positively diagnosed as identical were found to be alike in both reactions when tested, whereas assumedly fraternal pairs showed approximately the same degree of intra-pair variation as

TABLE 4

The frequencies of mirror-imaging in palm patterns and whorls on finger tips among twins and sibs. O = Observed; C = Calculated

GROUPS	NO. PAIRS		PALM PATTERNS					DIGIT PATTERNS					TOTAL
			Hyp.	Th. I	Int. II	Int. III	Int. IV	I	II	III	IV	V	
Identical twins ♀	137	O	3	2	2	4	4	0	1	3	4	0	23
		C	2.30	0.68	0.08	4.46	4.69	1.03	2.80	1.79	3.30	1.09	22.22
Identical twins ♂	90	O	4	0	1	6	3	0	5	2	1	0	22
		C	2.44	0	0.05	6.75	2.09	0.06	1.8	1.08	0.56	0.45	15.28
Fraternal twins ♀	61	O	0	0	0	0	1	0	1	2	0	2	6
		C	1.3	0.06	0	3.19	1.17	0.03	0.96	0.58	0.3	0.3	7.89
Fraternal twins ♂	35	O	1	0	0	3	6	1	2	1	1	1	16
		C	0.78	0.05	0	1.88	2.27	1.13	1.42	0.29	0.57	0.04	8.43
Sibs ♀	147	O	1	0	0	5	4	1	3	1	1	2	18
		C	3.67	0	0.13	11.23	4.9	0.71	2.99	1.98	2.46	0.17	28.24
Sibs ♂	149	O	6	0	1	5	9	1	2	4	1	2	31
		C	5.32	0.11	0.09	3.36	6.67	1.54	2.99	3.42	0.67	2.3	26.56

do single born paired sibs in populations of similar origin. Thus while we cannot prove that all pairs have been correctly diagnosed, the deviation is so slight that there can be little doubt that the great majority of pairs have been correctly classified. Some doubt existed at first concerning the zygosity of approximately 20 pairs, but further checks of dermatoglyphics, blood and photographs have cleared up most of these cases.

The sibs data were collected from 32 families. A grant from the National Research Council made possible the assembling of the sib and part of the twin data. The data on unrelated pairs were estimated from the prints of 300 right-handed males, 418 left-handed males, 288 right-handed females and 300 left-handed females, collected by Cromwell (Cromwell and Rife, 1942). All the prints and data used

TABLE 5

Average percentages of mirror-imaging among twins, sibs and unrelated pairs

TYPE OF PAIRS		AVERAGE PERCENT MIRROR-IMAGING
Identical twins ♀	O	1.68
	C	1.62
Identical twins ♂	O	2.44
	C	1.69
Fraternal twins ♀	O	0.98
	C	1.29
Fraternal twins ♂	O	0.98
	C	2.40
Paired sibs ♀	O	1.22
	C	1.92
Paired sibs ♂	O	2.08
	C	1.78
Unrelated pairs ♀	O	1.68
Unrelated pairs ♂	O	1.94

in the compilation of Tables 3, 4 and 5 are on file in the Genetics Laboratory at Ohio State University.

In this investigation the presence or absence of patterns on each of the five palmar areas, and the presence or absence of whorls on each of the five finger tip areas are included. On palms, both vestigial and true patterns are classed as patterns.

Table 4 lists the predicted and observed numbers of pairs in each group manifesting mirror-imaging for each area, and also the total. Note that among females the observed approximates the expected in each group, and that there are no significant differences between different groups. Among the males the observed frequencies exceed the calculated, but in no instance is the difference significant.

Table 5 shows the totals converted to average percentages for each group. In each group males show higher percentages than do females. This is what one might expect, in view of the fact that males in general show greater bimanual variation than do females. Within sexes, no significant variations are shown among the four groups. The story is the same as that obtained from Meyer-Heydenhagen's studies, and from the Lauterbach series. So-called mirror-imaging of dermatoglyphics occurs no more frequently in monozygotic twins than in unrelated pairs.

SUMMARY

Data assembled by three independent investigators and analyzed by different individuals agree in revealing that "mirror-imaging" in dermatoglyphics occurs no more frequently in monozygotic twins than in random pairs of unrelated individuals, sibs and fraternal twins. Thus occasional asymmetry reversals of dermatoglyphic features in one member of a pair of twins appear to be in no way related to the twinning process and are consequently of no value in twin diagnosis. Twins and paired sibs show approximately the same degree of such asymmetry reversals, thus indicating that conditions *in utero* peculiar to twins of both types have no affect on bilateral asymmetries of dermatoglyphics.

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DAILY DECREASES IN THE BODY TOTAL AND STEM LENGTHS OF NORMAL CHILDREN

BY HARRIET J. KELLY, PH.D., HELEN J. SOUDERS, M.S., A. THERESA JOHNSTON, M.S., LOUISE EMERSON BOUND, B.S., HELEN A. HUNSCHER, PH.D., AND ICIE G. MACY, PH.D.

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IN investigations of nutrition and chemical growth it is exceedingly important that the best techniques of linear measurement be used, for it is possible that length of the body may be found to bear a definite relationship with retention of some elements. Calcium and phosphorus are the principal minerals composing the skeletal tissues and studies of the utilization of these elements are frequently interpreted upon the basis of body length alone or an index such as physical type, which is influenced by this measurement. Ninety-nine per cent of the calcium in the body is in the bone structures, with a large percentage of the phosphorus. Even the amounts of constituents present in the skeleton in extremely small amounts, such as magnesium, which is believed to promote hardness of the bones, are related to the quantity of hard tissue in the body and may be found to be related to body length. In growth studies of only a few individuals, but over prolonged intervals of time, it is essential that every measurement be as accurate as possible. Degrees of reliability and objectivity of observations, though recognized early, have recently been emphasized as possible reasons for variability which might erroneously be interpreted as true differences. In making length measurements which are to be referred to other physical, or chemical and biological measurements, a collection of pseudo-significant data may result if differences in the time of day at which the records are obtained or in the relative amounts of activity by the different subjects prior to measurement are ignored.

For 165 years it has been known that the body may shrink in height during the day. In 1777, Montbeillard (1, 2) had longitudinal data on growth in stature and noted that height decreased during the day. From measurements of his son, he observed a loss of 38 mm. after a

night of dancing and recovery of the decrease after a twenty-four hour rest. Curtiss (3) reported the gain in stature following a night's rest, for 17, a 19, and a 21 year old boy who were measured at 10 p.m. and again the following morning at 6:30. The increases ranged from 9 mm. to 29 mm., with an average of 18.12 mm. The true cause of change in height during the hours of activity is not known, although some have considered muscle tone responsible. Whether chemical action, dehydration, and other physiologic processes play a rôle in the decrease in stature is uncertain.

Shrinkage in height following sustained functional activity during the day may be related to muscular fatigue. It is known that the varying decrease in muscle ability to respond which accompanies fatigue is due to a progressive loss of irritability and contractibility of the muscle. After a rest period there is a restoration of muscle tone and irritability (4). In 1925, Potter (5) reviewed the literature pertaining to exercise, fatigue and body position, in relation to cardiovascular manifestations, muscle strength and symmetry, acidity of urine, nitrogen products, toxins, vitamins, and methods of measurements. This author reported differences in length measurements for four Merrill-Palmer school boys, from 54 to 60 months of age. The boys were measured upon arrival at nursery school (semi-tired state), at noon after work and play periods (most-tired state), and again following an afternoon nap (most-rested state). The differences between the semi-tired and most-rested states were 7.1 mm. for recumbent length, 6.2 mm. for stature and 6.3 mm. for recumbent stem length. The differences between the most-rested and most-tired states were 14.2 mm. for recumbent length, 16.2 mm. for stature and 14.3 mm. for recumbent stem length.

Since that time the physiological and chemical consequences of exercise and fatigue have been studied extensively but daily shrinkage in recumbent total and stem lengths have not been reported in connection with them, nor have sex differences been studied. The possibility of misinterpretation arising from correlation of insufficiently controlled length measurements with other biological data has not been pointed out.

EXPERIMENTAL

During a comprehensive study of nutrition and chemical growth in childhood (6), morning and evening recumbent total and stem lengths were obtained for 10 normal children, 4 to 8 years old, at approximately two-week intervals over a period of eight months. The observations

were made to estimate the average daytime shrinkage in recumbent length, by normal children; to determine the relative decreases of the individuals; and to ascertain whether morning or evening measurements were most suitable for comparison with the results of biochemical observations. The children lived in a comfortable, congenial environment comparable to the average home situation, attended school and had ample periods of unrestricted play. They received generous diets composed of common foods and containing ample amounts of protein, calories, fiber, minerals, and vitamins.

Measurements of the nude subjects were taken on the Merrill-Palmer School measuring board (7), the first immediately upon arising in the morning and the other just before retiring for the night. The favorable conditions of dietary and environment, accompanied by a regular routine of living which included ten hours of sleep each night, in comfortable single beds, assured the fully rested state of the children at the time of the morning measurements. Of three observers, groups of two obtained the measurements for corresponding mornings and evenings, each person took two readings for each of the two measurements, alternating. Averages were determined for the four morning and four evening measurements and the difference determined.

The mean decreases in the recumbent lengths of the ten children are given in Table 1, together with their ages, lengths, weights, surface area, physical type, laxation rate, and basal heat production per day. The laxation rates (bowel movements per day) and studies of urinary etheral sulfur output (8) and disappearance of complex carbohydrates (9) indicate that intestinal intoxication did not contribute any abnormal factors to the results of the study. Since fatigue may depend upon the rate of oxygen consumption during metabolism in the body, the average basal heat production per 24 hours for the individual child is presented in Table 1. When referred to the Boothby-Sandiford standards, the average basal metabolic rate for the group of children was —5.3, a value that is considered within the normal range. The average body temperatures of the 10 children ranged from 98.2 to 99.0° F., their respiration rates from 17 to 27 and pluse rates from 70 to 94 per minute. Average systolic pressure for the individuals ranged from 83 to 98, diastolic from 57 to 70 mm. of mercury. These and other observations (6) demonstrate the conformance of the group with accepted standards of normal response.

TABLE 1

Morning to evening decreases in the recumbent lengths of 10 children

RECUMBENT LENGTH *Cm.*	AGE *Yrs.*	BODY WEIGHT *Kg.*	SURFACE AREA* *Sq. m.*	PHYSICAL TYPE†	LAXATION RATE‡	BASAL HEAT PRODUCTION *Cal./24 hrs.*	MEAN DECREASE IN RECUMBENT LENGTH Total *Mm.*	*Per cent*
138.0	8	28.14	1.056	0.0220	1.4	1078	18.0	1.3
120.8	6	21.24	0.851	0.0229	1.7	1020	13.0	1.1
120.5	6	22.62	0.872	0.0235	1.5	1000	14.1	1.2
120.4	8	24.32	0.900	0.0240	1.7	1025	14.7	1.2
118.6§	6	22.12	0.853	0.0237	1.1	929	13.2	1.1
117.1§	6	21.12	0.829	0.0236	1.3	926	12.8	1.1
116.0	5	19.16	0.789	0.0231	2.5	978	15.3	1.3
110.9§	5	19.07	0.764	0.0241	1.7	955	15.9	1.4
108.6	4	17.99	0.733	0.0241	2.0	983	17.4	1.6
106.8§	5	17.68	0.720	0.0244	1.8	866	13.0	1.2

* Dubois' formula.
† Cube root of weight divided by recumbent length.
‡ Defecations per 24 hours.
§ Girls.

The average decreases in total recumbent length ranged from 13 to 18 mm. and represented from 1.1 to 1.6 per cent of the corresponding total lengths of the children. The younger children showed the greater losses in length when referred to total length, but no relationship is evident between the length decreases and body weight, surface area, physical type, laxation rate, or basal heat production.

The average decreases found for the normal children are comparable with values for loss in stature which have been reported in the literature (2, 10, 11). Malling-Hansen (1) measured 70 school-age boys, 9 to 17 years old, over a two-year period and found their stature to be 1 cm. less when they went to bed than when they got up in the morning, of which 2 mm. was lost during the first hour. Wiener (10) found from measurements of two of his sons daily losses in stature of 1.3 cm. and 1.9 cm., of which 0.8 cm. and 0.9 cm. were lost during the first hour. A nap caused a partial return. Nylin (1) reported average decreases in the stature of 16 boys, 8 and 9 years old, of 0.13 cm. from 8:00 to 8:30 a. m.; 0.22 cm. from 8:00 to 9:00 a. m.; 0.65 cm. from 8:00 to 10:00 a. m.; 0.74 cm. from 8:00 to 11:00 a. m.; and 0.79 cm. from 8:00 to 12:00 a. m.

Palmer (12) measured the stature of 3 pre-school children at hourly intervals during the day for three to five consecutive days; he observed a decrease of 7.0 mm. the first hr.; 3.5 mm. the second hr.; 2.5 mm. the third hr.; 2.0 mm. the fourth hr.; and 25 mm. during 16 hours. Redfield and Meredith (10) reported on 22 pre-school children, 4 and 5 years

TABLE 2

Mean daily decreases in recumbent length shown by 608 semi-monthly measurements of 10 children (millimeters)

	TOTAL			STEM		
	Total	Girls	Boys	Total	Girls	Boys
Number	152	63	89	152	63	89
Minimum	6.4	6.4	7.9	4.0	4.0	6.4
Maximum	25.4	23.8	25.4	29.4	29.4	28.6
Mean	14.7	13.7	15.4	15.6	15.5	15.7
Standard deviation	4.1	3.8	4.1	4.4	5.0	4.0
Median	14.4	13.6	15.2	15.7	15.1	15.7
90th percentile	19.4	18.4	19.7	21.6	23.0	20.7

old. During the afternoon nap there was an increase ranging from 0 to 21 mm., with an average of 9.3 mm. in stature and from —4 to 23 mm., average 7.7 mm., in sitting height; a loss of from 1 to 15 mm., average 8.2 mm., in stature and from —10 to 20 mm., average 6.8 mm., in sitting height occurred during the first hour after the rest.

The results from frequency distributions drawn for all the differences in length of the ten children are shown in Table 2. The average difference found for recumbent total length falls between those for stature found by Malling-Hansen, by Curtiss, and by Palmer and is approximately the same as the average for Wiener's two sons. The values reported for decrease in stature over shorter periods of time and the sitting height and stem-length decreases reported for a part of the day are all less than the average recumbent total and stem length values found in this study. The mean differences between the morning and evening measurements of recumbent total and stem lengths for all of the children were 14.7 and 15.6 mm., respectively. These differences are approximately equivalent to three months' gain in recumbent length by the same children. The medians approximate the means in magnitude, indicating a symmetrical distribution. The 90th percentile values of 19.4 and 21. 6 mm. indicate the great differences that may occur between morning and evening measurements taken by the same observers. The data in Table 2 emphasize that erroneous conclusions may be made from body length measurements which are taken very carefully but without regard to time of day, particularly when trends of increase in length are studied in relation to other physiologic processes.

The decreases found in the recumbent stem lengths of the children are larger than the decreases in total length (Table 2); also, the variation shown by the range values is greater. Measurements of stem length are usually found to be much less consistent than those of total length, owing to variation produced by slight differences in position and the shifting of the fat pads in response to pressure against the buttocks.

Upon applying the critical ratio[1] technique to the data for boys and girls and to the data for total and stem lengths, critical ratios of 2.5 for recumbent total length and 0.2 for recumbent stem length, indicate that there may or may not be a real difference between the results

[1] $\frac{M_1 - M_2}{SE_{diff.}}$

found for boys and for girls. Disregarding sex, data for the two measurements provided a critical ratio of 1.8, indicating that the difference between decreases in total and stem length may or may not be real. Although these differences have not been proven statistically significant, their magnitude portrays a real need for taking anthropometric measurements when the body is in a fully rested state or when the subjects have been equally active, if growth is to be studied. The evidence indicates that morning measurements are the most reliable, for at other times during the day the amounts of activity or tissue changes prior to measurement, which are unmeasurable, are variable factors included in the measurement.

SUMMARY

Morning and evening recumbent total and stem lengths were obtained for 10 normal children, 6 boys and 4 girls, at approximately two week intervals for eight consecutive months. Application of the critical ratio technique to the data for boys and girls and to those for total and stem length indicated that the differences may or may not have been real.

The average decreases in total length per child during the day ranged from 13 to 18 mm. and represented from 1.1 to 1.6 per cent of the corresponding total lengths of the children. These differences are approximately equivalent to three months' gain in recumbent length by the same children and emphasize that erroneous conclusions may be made from body length measurements which are taken very carefully but without regard to time of day, particularly when trends of increase in length are studied in relation to other physiologic processes.

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CANCER AND MARITAL STATUS

BY HAROLD DORN

VARIOUS analyses of clinical records and official mortality statistics have indicated a relationship between marital status and mortality from cancer of certain specific sites. For example, the Registrar-General's Decennial Supplement for England and Wales reported that for the period 1930-32 the standardized death rates from cancer of the breast for married, widowed or divorced, and single females were, on a relative basis, 100, 107 and 134. On the other hand the corresponding indices of mortality from cancer of the uterus were 100, 131 and 55. For cancer of all genital organs the ratios were 100, 127 and 78.

At first thought these figures appear to suggest that childbearing decreases the likelihood of the development of breast cancer, but increases the likelihood of cancer of the genital organs. This conclusion was strengthened by the fact that for married women the death rate from cancer of the uterus increased with a decrease in social-economic status while the death rate from cancer of the breast varied directly with social-economic status. But the mortality rates for single women showed the same relative variation by social class as the rates for married women, which seemed to indicate that marital status was not the only factor affecting the development of cancer of the breast and genital organs.

Although the death rates for both married and single women were affected by social status, within each social class the mortality rate from cancer of the breast was higher among single women while the rate from cancer of the uterus was higher among married women.

Even though marital condition seemed to determine, in part at least, the relative prevalence of breast and uterine cancer it did not affect the total mortality from both combined. The mortality indices for married, widowed or divorced, and single women for cancer of the breast and genital organs together were 100, 117, and 105. Furthermore, for all forms of cancer the corresponding ratios were 100, 114, and 101.

Some additional information concerning the relationship of cancer to marital status can be obtained from the vital statistics of Australia. Beginning in 1921 persons who died from cancer were classified as never married, married without children, and married with children. Moreover, at the census of 1921 information concerning the number of children ever born was obtained so that it was possible to separate the population into the three classes used in the tabulation of the mortality records.

Due to the relatively small population in Australia it seemed desirable to use deaths for a five-year period in the computation of mortality rates for cancer. Accordingly the deaths for 1919 and 1920 were distributed among the three marital groups proportionately to the deaths for 1921-1923. Death rates for all forms of cancer computed in this way are shown in Table 1.

TABLE 1

Crude and standardized death rates from cancer by sex and marital status, Australia, 1919-1923

MARITAL STATUS	CRUDE RATE		STANDARDIZED RATE		RATIO OF STANDARDIZED RATES	
	Male	*Female*	*Male*	*Female*	*Male*	*Female*
Never married.....	120	112	168	179	103	110
Married without children	150	170	182	183	112	112
Married with children..	196	183	163	163	100	100
Total	170	167	165	167	...	...

Rates are per 100,000 population. The total female population of Australia, 1921, was used as the standard.

For both males and females the married persons with children have the lowest death rate from cancer while the married persons without children have the highest rate. The variation, however, is not great. Indeed, for males the mortality rate for single males is only 3 percent higher than the rate for married males with children. It is not immediately obvious why the death rate for married persons without children should be higher than that for the other two groups.

TABLE 2

Standardized death rates from cancer by primary site and marital status, Australia, 1919-1923

PRIMARY SITE	NEVER MARRIED	MARRIED		NEVER MARRIED	MARRIED	
		Without children	With children		Without children	With children
	Male			*Female*		
Buccal cavity.....	24	21	18	2	2	2
Stomach, liver.....	70	74	70	49	46	49
Intestines	21	26	23	25	27	25
Skin	8	7	8	5	4	5
All other organs.....	44	55	43	27	26	26
Female genital	..	..	..	30	44	33
Breast	..	..	..	40	34	24
All sites.....	168	182	163	179	183	163
Total number of deaths	2482	1109	8750	1675	1219	8581

Rates are per 100,000 population. The total female population of Australia, 1921, was used as the standard.

Table 2 presents mortality rates for specific sites. With the exception of cancer of the breast and female genital organs there is very little difference in the mortality of the three groups. The greatest relative variation is for cancer of the breast. If the mortality rate of married women with children is taken as 100, the corresponding relative indices of mortality for the childless married women and the spinsters are 142 and 167. The same relationship exists at each age group after 35 years. Among women 25-34 years of age the death rate from cancer of the breast is slightly higher for married women with children, 2.4 per 100,000 population compared with 2.0 for single women and 1.8 for married women without children, but the number of deaths in this age group is relatively small so that the difference is not of much importance.

These observations are in agreement with similar data for England and Wales, and lend support to the belief that the bearing of children decreases the likelihood of death from cancer of the breast. It is not possible from the available data to determine whether one child is as effective as 10 for this purpose.

If motherhood is an important factor in decreasing the incidence of cancer of the breast it might seem that married women without

children should have a death rate as high as single women whereas it actually is about 15 percent less. It has been known for many years that married persons live longer than unmarried, so that the lower death rate from cancer of the brest of the childless married women as compared with the rate of single women may merely reflect the health advantage of married women. Moreover the fact that a married women is childless does not necessarily mean that she has never been pregnant although such an assumption would probably be true in most instances. It is apparent that pregnancy history is only one of the factors influencing the chances of dying from cancer of the breast so that its effect should not be unduly emphasized.

Although the death rate from cancer of the female genital organs is higher among married than among single women in Australia just as it is in England, the subdivision of the married women into those with and without children reveals that the higher rate among married women is due largely to the high rate among childless married women whose rate is nearly 50 percent higher than the rate for single women. The rate for women with children is only 10 percent greater than the rate for single women. These data do not indicate that childbearing plays an important rôle in the development of cancer of the female genital organs. The results might be altered somewhat if data were available for uterine cancer alone, but since cancer of this site accounts for about 85 percent of all deaths from cancer of the female genital organs the death rate from cancer of the ovaries, vulva and vagina would have to be considerably higher among single than among married women to alter appreciably the rate shown in Table 2.

During the childbearing ages, and immediately thereafter, however, the death rate from cancer of the female genital organs is definitely higher among married women with children than it is among single women. For specific ages the rates per 100,000 population are as follows:

	25-34	*35-44*	*45-54*	*55-64*	*65-74*	*75 and over*
Never married	2.3	16.9	43.9	63.7	94.7	108.8
Married without children	4.0	30.3	69.6	89.1	131.9	85.6
Married with children...	4.1	20.1	48.8	76.2	83.0	83.2

For women from 25-64 years of age the death rates from cancer of the female genital organs are 17.4, 34.0, and 30.6 respectively for

single women, married women without children, and married women with children. Although the rate for single women in this age group is considerably less than the rate for married women, the married women without children have the highest rate of all.

It is possible to obtain data which are approximately comparable to these for a 5-year period centered around the census data in 1933. Unfortunately information concerning the issue of married women was not collected at that census so that it is necessary to estimate the proportion of childless married women. This was done by assuming that the proportion of childless married women in the living population was the same as the proportion among the dead from all causes. This assumption is not strictly true since the death rate of the childless married women is slightly higher than the rate for the married women with children. Consequently the estimated number of living childless married women is somewhat too large so that the death rates from cancer will be lowered for the childless, but increased for the women with children. This error is not very important, but it should be borne in mind during the following discussion. The same procedure was used to estimate the proportion of childless married men.

During the 5-year period 1931-1935, the mortality rates from cancer for single men and childless married men exceeded the corresponding rate for married men with children by about 15 percent. This agrees substantially with the results for the previous decade. Very little difference existed between the rates for single and childless married men.

The mortality rates for all forms of cancer of married women with children, single women, and childless married women were relatively 100, 109, and 127. The three groups have the same rank order with respect to mortality from cancer as for 1919-23, but the relative differences are somewhat greater.

The relative indices of mortality from cancer of the breast, uterus and other female genital organs are:

	Married women with children	*Single women*	*Childless married women*
Breast	100	145	137
Uterus	100	80	137
Other female genital organs	100	203	215

Just as in 1919-23 the death rate from cancer of the breast for spinsters and childless married women definitely exceeded the rate for married women with children, the same is true for cancer of the female genital organs excluding the uterus; most of these deaths result from cancer of the ovaries. Deaths from cancer of these sites are only about 5 percent of the total number of deaths from cancer among females, but the relative difference in the rates for women with and without children is larger than that for any other form of cancer.

This large difference in mortality rates from cancer of the ovaries, vagina, and vulva undoubtedly accounts for the small difference in the rates for cancer of the entire genital system among spinsters and married women with children in 1919-23. Cancer of the uterus is definitely less frequent among single women than among married women with children, but childless married women have the highest rates of all. The latter was also true ten years previously.

In summary it may be stated that the ameliorative effect of marriage upon health seems to be due to childbearing rather than to the fact of marriage itself, at least insofar as cancer is concerned. For both males and females, those who marry and have children are less likely to die from cancer than those who remain single, but those who marry and do not have children have the highest death rates. The death rates for married women with children are especially low relative to the rates for the other two groups for cancer of the breast and genital organs exclusive of the uterus. For cancer of the latter site single women have a rate about 20 percent less than the rate for married women with children, a relationship probably arising from the hazards of childbearing. But even for cancer of this site the childless married women have the highest rate.

The primary purpose of this paper is to point out certain differences in the mortality from cancer among women with varying marital history; it is not the intention at this time to attempt to explain these observed differences. Although the actual differences can be best established by statistical methods, the explanation of the differences must rest upon clinical observations.

The actual process of bearing children almost certainly is not the sole explanation of the differences in mortality rates although it possibly plays an important rôle in the development of cancer of the cervix. Moreover, many of the married women who do not bear children are

probably involuntarily sterile and thus differ physiologically from married women who bear children. The extent to which physiological causes of sterility also affect the development of cancer is unknown and can be only speculated about at the present time.

RECENT LITERATURE

USEFUL IN THE STUDY OF HUMAN BIOLOGY

In this department will be noticed the books and reprints which are currently received at the Editorial Office. Publications intended for notice here should be addressed to Dr. Lowell J. Reed, Editor of HUMAN BIOLOGY, 615 North Wolfe Street, Baltimore, Maryland, U. S. A.

I. EVOLUTION AND GENETICS

1. *Evolution — General Principles*

GREGORY, JOSEPH TRACY. Pliocine Vertebrates from Big Spring Canyon, South Dakota. *University of California Publications. Bulletin of the Department of Geological Series*, Vol. 26, No. 4. *Berkeley* (Univ. Calif. Press), 1942. Pp. 307-446 + 3 plates. 10½ × 6¾ inches. $2.00 (paper). [Bibliography of 4¼ pages.]

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